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5. INHALATION ROUTE

This chapter presents data and recommendations for inhalation rates that can be used to assess exposure to contaminants in air. The studies discussed in this chapter have been classified as key or relevant. Key studies are used as the basis for deriving recommendations and the relevant studies are included to provide additional background and perspective. The recommended inhalation rates are summarized in Section 5.2.4 and cover adults, children, and outdoor workers/athletes.

Inclusion of this chapter in the Exposure Factors Handbook does not imply that assessors will always need to select and use inhalation rates when evaluating exposure to air contaminants. In fact, it is unnecessary to calculate inhaled dose when using dose-response factors from Integrated Risk Information System (IRIS) (U.S. EPA, 1994). This is due to the fact that IRIS methodology accounts for inhalation rates in the development of "dose-response" relationships. When using IRIS for inhalation risk assessments, "dose-response" relationships require only an average air concentration to evaluate health concerns:

- For non-carcinogens, IRIS uses Reference Concentrations (RfC) which are expressed in concentration units. Hazard is evaluated by comparing the inspired air concentration to the RfC.

- For carcinogens, IRIS uses unit risk values which are expressed in inverse concentration units. Risk is evaluated by multiplying the unit risk by the inspired air concentration.

Detailed descriptions of the IRIS methodology for derivation of inhalation reference concentrations can be found in two methods manuals produced by the Agency (U.S. EPA, 1992; 1994).

IRIS employs a default inhalation rate of 20 m^3/day. This is greater than the recommendated value in this chapter. When using IRIS, adjustments of dose-response relationships using inhalation rates other than the default, 20 m^3/day, are not currently recommended. There are instances where the inhalation rate data presented in this chapter may be used for estimating average daily dose. For example, the inhalatino average daily dose is often estimated in cases where a compative pathway analysis is desired or to determine a total dose by adding across pathways in cases where RfCs and unit risk factors are not available.

5.1. EXPOSURE EQUATION FOR INHALATION

For those cases where the average daily dose (ADD) needs to be estimated, the general equation is:

$$ADD = [[C \times IR \times ED] / [BW \times AT]] \qquad \text{(Eqn. 5-1)}$$

where:

ADD	=	average daily dose (mg/kg-day);
C	=	contaminant concentration in inhaled air ($\mu g/m^3$);
IR	=	inhalation rate (m^3/day);
ED	=	exposure duration (days);
BW	=	body weight (kg); and
AT	=	averaging time (days), for non-carcinogenic effects AT = ED, for carcinogenic or chronic effects AT = 70 years or 25,550 days (lifetime).

The average daily dose is the dose rate averaged over a pathway-specific period of exposure expressed as a daily dose on a per-unit-body-weight basis. The ADD is used for exposure to chemicals with non-carcinogenic non-chronic effects. For compounds with carcinogenic or chronic effects, the lifetime average daily dose (LADD) is used. The LADD is the dose rate averaged over a lifetime. The contaminant concentration refers to the concentration of the contaminant in inhaled air. Exposure duration refers to the total time an individual is exposed to an air pollutant.

5.2. INHALATION RATE

5.2.1. Background

The Agency defines exposure as the chemical concentration at the boundary of the body (U.S. EPA, 1992). In the case of inhalation, the situation is complicated by the fact that oxygen exchange with carbon dioxide takes place in the distal portion of the lung. The anatomy and physiology of the respiratory system diminishes the pollutant concentration in inspired air (potential dose) such that the amount of a pollutant that actually enters the body through the lung (internal dose) is less than that measured at the boundary of the body (Figure 5-1). When constructing risk assessments that concern the inhalation route of exposure, one must be aware if any adjustments have been employed in the estimation of the pollutant concentration to account for this reduction in potential dose.

The respiratory system is comprised of three regions: nasopharyngeal, tracheobronchial, and pulmonary. The

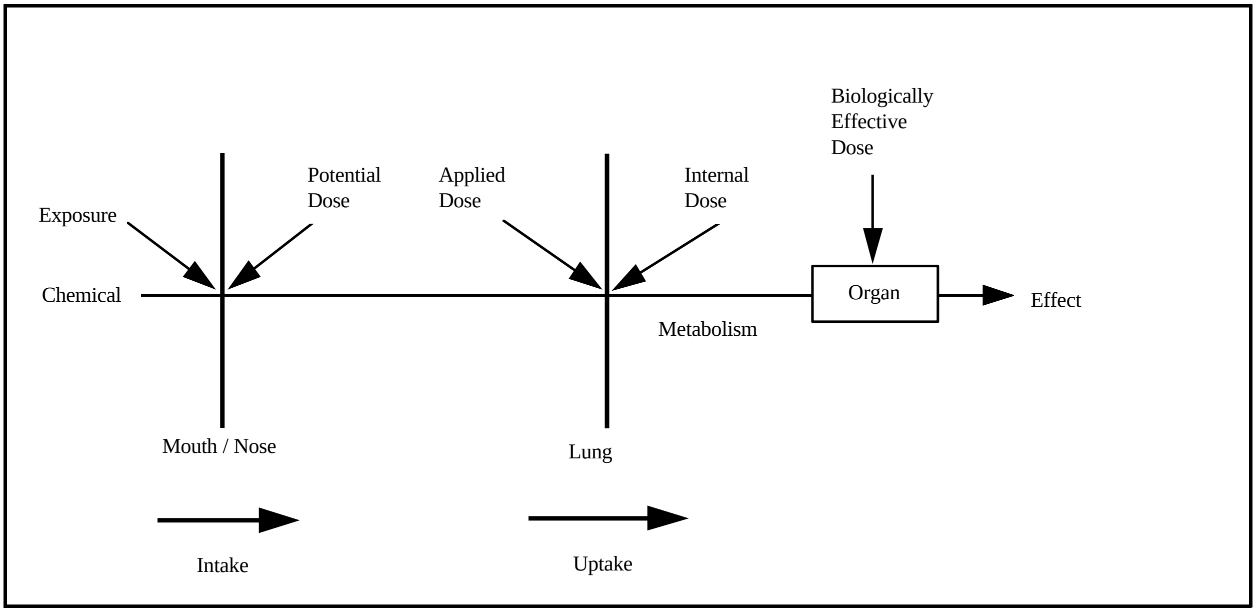

Figure 5-1. Schematic of Dose and Exposure: Respiratory Route

Source: U.S. EPA, 1992.

nasopharyngeal region extends from the nose to the larynx. The tracheobronchial region forms the conducting airways between nasopharynx and alveoli where gas exchange occurs. It consists of the trachea, bronchi, and bronchioles. The pulmonary regions consists of the acinus which is the site where gas exchange occurs; it is comprised of respiratory bronchioles, alveolar ducts and sacs, and alveoli. A detailed discussion of pulmonary anatomy and physiology can be found in: Benjamin (1988) and U.S. EPA (1989 and 1994) .

Each region in the respiratory system can be involved with removing pollutants from inspired air. The nasopharyngeal region filters out large inhaled particles, moderates the temperature, and increases the humidity of the air. The surface of the tracheobronchial region is covered with ciliated mucous secreting cells which forms a mucociliary escalator that moves particles from deep regions of the lung to the oral cavity where they may be swallowed and then excreted. The branching pattern and physical dimensions of the these airways determine the pattern of deposition of airborne particles and absorption of gases by the respiratory tract. They decrease in diameter as they divide into a bifurcated branching network dilutes gases by axial diffusion of gases along the streamline of airways and radial diffusion of gases due to an increase in cross sectional area of the lungs. The velocity of the airstream in this decreasing branching network creates a turbulent force such that airborne particles can be deposited along the walls of these airways by impaction, interception, sedimentation, or diffusion depending on their size. The pulmonary region contains macrophages which engulf particles and pathogens that enter this portion of the lung.

Notwithstanding these removal mechanisms, both gaseous and particulate pollutants can deposit in various regions of the lung. Both the physiology of the lung and the chemistry of the pollutant influences where the pollutant tends to deposit.

Gaseous pollutants are evenly dispersed in the air stream. They come into contact with a large portion of the lung. Generally, their solubility and reactivity determines where they deposit in the lung. Water soluble and chemically reactive gases tend to deposit in the upper respiratory tract. Lipid soluble or non-reactive gases usually are not removed in the upper airways and tend to deposit in the distal portions of the lung. Gases can be absorbed into the blood stream or react with lung tissue. Gases can be removed from the lung by reaction with tissues or by expiration. The amount of gas retained in the lung or other parts of the body is mainly due to their solubility in blood.

Chemically, particles are quite heterogenous. They range from aqueous soluble particles to solid insoluble particles. Their size, chemical composition, and the physical forces of breathing dictate where they tend to deposit in the lung. Large particles, those with a diameter of greater than 0.5 micrometers (um), not filtered out in the nasopharynx, tend to deposit in the upper respiratory tract at airway branching points due to impaction. The momentum of these particles in the air stream is such that they tend to collide with the airway wall at branching points in the tracheobronchial region of the lung. Those particles not removed from the airstream by impaction will likely be deposited in small bronchi and bronchioles by sedimentation, a process where by particles settle out of the airstream due to the decrease in airstream velocity and the gravitational force on the particles. Small particles, less than 0.2 um, acquire a random motion due to bombardment by air molecules. This movement can cause particles to be deposited on the wall of an air way throughout the lungs.

A special case exists for fibers. Fibers can deposit along the wall of an airway by a process known as interception. This occurs when a fiber makes contact with an airway wall. The likelihood of interception increases as airway diminish in diameter. Fiber shape influences deposition too. Long, thin, straight fibers tend to deposit in the deep region of the lung compared to thick or curved fibers.

The health risk associated with human exposure to airborne toxics is a function of concentration of air pollutants, chemical species, duration of exposure, and inhalation rate. The dose delivered to target organs (including the lungs) , the biologically effective dose, is dependent on the potentail dose, the applied dose and the internal dose (Figure 5-1) A detailed discussion of this concept can be found in Guidelines for Exposure Assessment (U.S. EPA, 1992).

The estimation of applied dose for a given air pollutant is dependent on inhalation rate, commonly described as ventilation rate (VR) or breathing rate. VR is usually measured as minute volume, the volume in liters of air exhaled per minute(V_E). $\dot{V}_E$ is the product of the number of respiratory cycles in a minute and the volume of air respired during each respiratory cycle, the tidal volume(V_T).

When interested in calculating internal dose, assessors must consider the alveolar ventilation rate. This is the amount of air available for exchange with alveoli per unit time. It is equivalent to the tidal volume(V_T) minus the anatomic dead space of the lungs (the space containing air that does not come into contact with the alveoli). Alveolar ventilation is approximately 70 percent of total ventilation; tidal volume is approximately 500 milliliters (ml) and the amount of anatomic dead space in the lungs is approximately 150 ml, approximately 30% of the amount of air inhaled (Menzel and Amdur, 1986).

Breathing rates are affected by numerous individual characteristics, including age, gender, weight, health status, and levels of activity (running, walking, jogging, etc.). VRs are either measured directly using a spirometer and a collection system or indirectly from heart rate (HR) measurements. In many of the studies described in the following sections, HR measurements are usually correlated with VR in simple and multiple regression analysis.

The available studies on inhalation rates are summarized in the following sections. Inhalation rates are reported for adults and children (including infants) performing various activities and outdoor workers/ athletes. The activity levels have been categorized as resting, sedentary, light, moderate, and heavy. In most studies, the sample population kept diaries to record their physical activities, locations, and breathing rates. Ventilation rates were either measured, self-estimated or predicted from equations derived using VR-HR calibration relationships.

5.2.2. Key Inhalation Rate Studies

Linn et al. (1992) - Documentation of Activity Patterns in "High-Risk" Groups Exposed to Ozone in the Los Angeles Area - Linn et al. (1992) conducted a study that estimated the inhalation rates for "high-risk" subpopulation groups exposed to ozone (O_3) in their daily activities in the Los Angeles area. The population surveyed consisted of seven subject panels: *Panel 1*: 20 healthy outdoor workers (15 males, 5 females, ages 19-50 years); *Panel 2*: 17 healthy elementary school students (5 males, 12 females, ages 10-12 years); *Panel 3*: 19 healthy high school students (7 males, 12 females, ages 13-17 years); *Panel 4*: 49 asthmatic adults (clinically mild, moderate, and severe, 15 males, 34 females, ages 18-50 years); *Panel 5*: 24 asthmatic adults from 2 neighborhoods of contrasting O_3 air quality (10 males, 14 females, ages 19-46 years); *Panel 6*: 13 young asthmatics (7 males, 6 females, ages 11-16 years); *Panel 7*: construction workers (7 males, ages 26-34 years).

Initially, a calibration test was conducted, followed by a training session. Finally, a field study was conducted which involved subjects' collecting their own heart rate and diary data. During the calibration tests, VR and HR were measured simultaneously at each exercise level. From the calibration data an equation was developed using linear regression analysis to predict VR from measured HR (Linn et al., 1992).

In the field study, each subject (except construction workers) recorded in diaries: their daily activities, change in locations (indoors, outdoors, or in a vehicle), self-estimated breathing rates during each activity/location, and time spent at each activity/location. Healthy subjects recorded their HR once every 60 seconds, Asthmatic subjects recorded their diary information once every hour using a Heart Watch. Construction workers dictated their diary information to a technician accompanying them on the job. Subjective breathing rates were defined as slow (walking at their normal pace); medium (faster than normal walking); and fast (running or similarly strenuous exercise). Table 5-1 presents the calibration and field protocols for self-monitoring of activities for each subject panel.

Table 5-2 presents the mean VR, the 99th percentile VR, and the mean VR at each subjective activity level (slow, medium, fast). The mean VR and 99th percentile VR were derived from all HR recordings (that appeared to be valid) without considering the diary data. Each of the three activity levels was determined from both the concurrent diary data and HR recordings by direct calculation or regression (Linn et al., 1992). The mean VR for healthy adults was 0.78 m^3/hr while the mean VR for asthmatic adults was 1.02 m^3/hr (Table 5-2). The preliminary data for construction workers indicated that during a 10-hr work shift, their mean VR (1.50 m^3/hr) exceeded the VRs of all other subject panels (Table 5-2). Linn et al. (1992) reported that the diary data showed that most individuals except construction workers spent most of their time (in a typical day) indoors at slow activity level. During slow activity, asthmatic subjects had higher VRs than healthy subjects, except construction workers (Table 5-2). Also, Linn et al. (1992) reported that in every panel, the predicted VR correlated significantly with the subjective estimates of activity levels.

Table 5-1. Calibration and Field Protocols for Self-Monitoring of Activities Grouped by Subject Panels

Panel	Calibration Protocol	Field Protocol
Panel 1 - Healthy Outdoor Workers - 15 female, 5 male, age 19-50	Laboratory treadmill exercise tests, indoor hallway walking tests at different self-chosen speeds, 2 outdoor tests consisted of 1-hour cycles each of rest, walking, and jogging.	3 days in 1 typical summer week (included most active workday and most active day off); HR recordings and activity diary during waking hours.
Panel 2 - Healthy Elementary School Students - 5 male, 12 female, age 10-12	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Saturday, Sunday and Monday (school day) in early autumn; HR recordings and activity diary during waking hours and during sleep.
Panel 3 - Healthy High School Students - 7 male, 12 female, age 13-17	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Same as Panel 2, however, no HR recordings during sleep for most subjects.
Panel 4 - Adult Asthmatics, clinically mild, moderate, and severe - 15 male, 34 female, age 18-50	Treadmill and hallway exercise tests	1 typical summer week, 1 typical winter week; hourly activity/health diary during waking hours; lung function tests 3 times daily; HR recordings during waking hours on at least 3 days (including most active work day and day off).
Panel 5 - Adult Asthmatics from 2 neighborhoods of contrasting O_3 air quality - 10 male, 14 female, age 19-46	Treadmill and hallway exercise tests	Similar to Panel 4, personal NO_2 and acid exposure monitoring included. (Panels 4 and 5 were studied in different years, and had 10 subjects in common).
Panel 6 - Young Asthmatics - 7 male, 6 female, age 11-16	Laboratory exercise tests on bicycles and treadmills	Similar to Panel 4, summer monitoring for 2 successive weeks, including 2 controlled exposure studies with few or no observable respiratory effects.
Panel 7 - Construction Workers - 7 male, age 26-34	Performed similar exercises as Panel 2 and 3, and also performed job-related tests including lifting and carrying a 9-kg pipe.	HR recordings and diary information during 1 typical summer work day.

Source: Linn et al., 1992

Table 5-2. Subject Panel Inhalation Rates by Mean VR, Upper Percentiles, and Self-Estimated Breathing Rates

Panel	Inhalation Rates (m^3/hr)					
	N[a]	Mean VR (m^3/hr)	99th Percentile VR	Mean VR at Activity Levels (m^3/hr)[b]		
				Slow	Medium[c]	Fast[c]
Healthy						
1 - Adults	20	0.78	2.46	0.72	1.02	3.06
2 - Elementary School Students	17	0.90	1.98	0.84	0.96	1.14
3 - High School Students	19	0.84	2.22	0.78	1.14	1.62
7 - Construction Workers[c]	7	1.50	4.26	1.26	1.50	1.68
Asthmatics						
4 - Adults	49	1.02	1.92	1.02	1.68	2.46
5 - Adults[d]	24	1.20	2.40	1.20	2.04	4.02
6 - Elementary and High School Students	13	1.20	2.40	1.20	1.20	1.50

[a] Number of individuals in each survey panel.
[b] Some subjects did not report medium and/or fast activity. Group means were calculated from individual means (i.e., give equal weight to each individual who recorded any time at the indicated activity level).
[c] Construction workers recorded only on 1 day, mostly during work, while others recorded on $\geq$ 1 work or school day and $\geq$ 1 day off.
[d] Excluding subjects also in Panel 4.

Source: Linn et al., 1992.

A limitation of this study is that calibration data may overestimate the predictive power of HR during actual field monitoring. The wide variety of exercises in everyday activities may result in greater variation of the VR-HR relationship than calibrated. Another limitation of this study is the small sample size of each subpopulation surveyed. An advantage of this study is that diary data can provide rough estimates of ventilation patterns which are useful in exposure assessments. Another advantage is that inhalation rates were presented for various subpopulations (i.e., healthy outdoor adult workers, healthy children, asthmatics, and construction workers).

Spier et al. (1992) - Activity Patterns in Elementary and High School Students Exposed To Oxidant Pollution - Spier et al. (1992) investigated activity patterns of 17 elementary school students (10-12 years old) and 19 high school students (13-17 years old) in suburban Los Angeles from late September to October (oxidant pollution season). Calibration tests were conducted in supervised outdoor exercise sessions. The exercise sessions consisted of 5 minutes for each: rest, slow walking, jogging, and fast walking. HR and VR were measured during the last 2 minutes of each exercise. Individual VR and HR relationships for each individual were determined by fitting a regression line to HR values and log VR values. Each subject recorded their daily activities, change in location, and breathing rates in diaries for 3 consecutive days. Self-estimated breathing rates were recorded as slow (slow walking), medium (walking faster than normal), and fast (running). HR was recorded during the 3 days once per minute by wearing a Heart Watch. VR values for each self-estimated breathing rate and activity type were estimated from the HR recordings by employing the VR and HR equation obtained from the calibration tests.

The data presented in Table 5-3 represent HR distribution patterns and corresponding predicted VR for each age group during hours spent awake. At the same self-reported activity levels for both age groups, inhalation rates were higher for outdoor activities than for indoor activities. The total hours spent indoors by high school students (21.2 hours) were higher than for elementary school students (19.6 hours). The converse was true for outdoor activities; 2.7 hours for high school students, and 4.4 hours for elementary school students (Table 5-4). Based on the data presented in Tables 5-3 and 5-4, the average activity-specific inhalation rates for elementary (10-12 years) and high school (13-17 years) students were calculated in Table 5-5. For elementary school students, the average daily inhalation rates (based on indoor and outdoor locations) are 15.8 m^3/day for light activities, 4.62 m^3/day for moderate activities, and 0.98 m^3/day for heavy activities. For high school students the daily inhalation rates for light, moderate, and heavy activities are estimated to be 16.4 m^3/day, 3.1 m^3/day, and 0.54 m^3/day, respectively (Table 5-5).

Table 5-3. Distribution of Predicted IR by Location and Activity Levels for Elementary and High School Students

Age (yrs)	Student	Location	Activity Level	% Recorded Time[a]	Inhalation Rates (m^3/hr)			
						Percentile Rankings[b]		
					Mean ± SD	1st	50th	99.9th
10-12	EL[c] (n[d]=17)	Indoors	slow	49.6	0.84 ± 0.36	0.18	0.78	2.34
			medium	23.6	0.96 ± 0.42	0.24	0.84	2.58
			fast	2.4	1.02 ± 0.60	0.24	0.84	3.42
		Outdoors	slow	8.9	0.96 ± 0.54	0.36	0.78	4.32
			medium	11.2	1.08 ± 0.48	0.24	0.96	3.36
			fast	4.3	1.14 ± 0.60	0.48	0.96	3.60
13-17	HS[c] (n[d]=19)	Indoors	slow	70.7	0.78 ± 0.36	0.30	0.72	3.24
			medium	10.9	0.96 ± 0.42	0.42	0.84	4.02
			fast	1.4	1.26 ± 0.66	0.54	1.08	6.84[c]
		Outdoors	slow	8.2	0.96 ± 0.48	0.42	0.90	5.28
			medium	7.4	1.26 ± 0.78	0.48	1.08	5.70
			fast	1.4	1.44 ± 1.08	0.48	1.02	5.94

[a] Recorded time averaged about 23 hr per elementary school student and 33 hr. per high school student, over 72-hr. periods.
[b] Geometric means closely approximated 50th percentiles; geometric standard deviations were 1.2-1.3 for HR, 1.5-1.8 for VR.
[c] EL = elementary school student; HS = high school student.
[d] N = number of students that participated in survey.
[e] Highest single value.

Source: Spier et al., 1992.

Table 5-4. Average Hours Spent Per Day in a Given Location and Activity Level for Elementary (EL) and High School (HS) Students

Student (EL[a], n[c]=17; HS[b], N[c]=19)	Location	Activity Level			Total Time Spent (hrs/day)
		Slow	Medium	Fast	
EL	Indoor	16.3	2.9	0.4	19.6
EL	Outdoor	2.2	1.7	0.5	4.4
HS	Indoor	19.5	1.5	0.2	21.2
HS	Outdoor	1.2	1.3	0.2	2.7

[a] Elementary school (EL) students were between 10-12 years old.
[b] High school (HS) students were between 13-17 years old.
[c] N corresponds to number of school students.

Source: Spier et al., 1992.

Table 5-5. Distribution Patterns of Daily Inhalation Rates for Elementary (EL) and High School (HS) Students Grouped by Activity Level

Students	Age (yrs)	Location	Activity type[a]	Mean IR[b] (m^3/day)	Percentile Rankings 1st	50th	99.9th
EL (n[c]=17)	10-12	Indoor	Light	13.7	2.93	12.71	38.14
			Moderate	2.8	0.70	2.44	7.48
			Heavy	0.4	0.096	0.34	1.37
EL		Outdoor	Light	2.1	0.79	1.72	9.50
			Moderate	1.84	0.41	1.63	5.71
			Heavy	0.57	0.24	0.48	1.80
HS (n=19)	13-17	Indoor	Light	15.2	5.85	14.04	63.18
			Moderate	1.4	0.63	1.26	6.03
			Heavy	0.25	0.11	0.22	1.37
HS		Outdoor	Light	1.15	0.50	1.08	6.34
			Moderate	1.64	0.62	1.40	7.41
			Heavy	0.29	0.096	0.20	1.19

[a] For this report, activity type presented in Table 5-2 was redefined as light activity for slow, moderate activity for medium, and heavy activity for fast.

[b] Daily inhalation rate was calculated by multiplying the hours spent at each activity level (Table 5-4) by the corresponding inhalation rate (Table 5-3).

[c] Number of elementary (EL) and high school students (HS).

Source: Adapted from Spier et al., 1992 (Generated using data from Tables 5-3 and 5-4).

A limitation of this study is the small sample size. The results may not be representative of all children in these age groups. Another limitation is that the accuracy of the self-estimated breathing rates reported by younger age groups is uncertain. This may affect the validity of the data set generated. An advantage of this study is that inhalation rates were determined for children and adolescents. These data are useful in estimating exposure for the younger population.

Adams (1993) - Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities - Adams (1993) conducted research to accomplish two main objectives: (1) identification of mean and ranges of inhalation rates for various age/gender cohorts and specific activities; and (2) derivation of simple linear and multiple regression equations used to predict inhalation rates through other measured variables: heart rate (HR), breathing frequency (f_B), and oxygen consumption (V_{O2}). A total of 160 subjects participated in the primary study. There were four age dependent groups: (1) children 6 to 12.9 years old, (2) adolescents between 13 and 18.9 years old, (3) adults between 19 and 59.9 years old, and (4) seniors >60 years old (Adams, 1993). An additional 40 children from 6 to 12 years old and 12 young children from 3 to 5 years old were identified as subjects for pilot testing purposes in this age group (Adams, 1993).

Resting protocols conducted in the laboratory for all age groups consisted of three phases (25 minutes each) of lying, sitting, and standing. They were categorized as resting and sedentary activities. Two active protocols, moderate (walking) and heavy (jogging/ running) phases, were performed on a treadmill over a progressive continuum of intensities made up of 6 minute intervals, at 3 speeds, ranging from slow to moderately fast. All protocols involved measuring VR, HR, f_B (breathing frequency), and V_{O2} (oxygen consumption). Measurements were taken in the last 5 minutes of each phase of the resting protocol, and the last 3 minutes of the 6 minute intervals at each speed designated in the active protocols.

In the field, all children completed spontaneous play protocols, while the older adolescent population (16-18 years) completed car driving and riding, car maintenance (males), and housework (females) protocols. All adult females (19-60 years) and most of the senior (60-77 years) females completed housework, yardwork, and car driving and riding protocols. Adult and senior males completed car driving and riding, yardwork, and mowing protocols. HR, VR, and f_B were measured during each protocol. Most protocols were conducted for 30 minutes. All the active field protocols were conducted twice.

During all activities in either the laboratory or field protocols, IR for the children's group revealed no significant gender differences, but those for the adult groups demonstrated gender differences. Therefore, IR data presented in Appendix Tables 5A-1 and 5A-2 were categorized as young children, children (no gender),and for adult female, and adult male by activity levels (resting, sedentary, light, moderate, and heavy). These categorized data from the Appendix tables are summarized as IR in m^3/hr in Tables 5-6 and 5-7. The laboratory protocols are shown in Table 5-6. Table 5-7 presents the mean inhalation rates by group and activity levels (light, sedentary, and moderate) in field protocols. A comparison of the data shown in Tables 5-6 and 5-7 suggest that during light and sedentary activities in laboratory and field protocols, similar inhalation rates were obtained for adult females and adult males. Accurate predictions of IR across all population groups and activity types were obtained by including body surface area (BSA), HR, and f_B in multiple regression analysis (Adams, 1993). Adams (1993) calculated BSA from measured height and weight using the equation:

$$BSA = Height^{(0.725)} \times Weight^{(0.425)} \times 71.84. \qquad \text{(Eqn. 5-2)}$$

A limitation associated with this study is that the population does not represent the general U.S. population. Also, the classification of activity types (i.e., laboratory and field protocols) into activity levels may bias the inhalation rates obtained for various age/gender cohorts. The estimated rates were based on short-term data and may not reflect long-term patterns. An advantage of this study is that it provides inhalation data for all age groups.

Linn et al. (1993) - Activity patterns in Ozone Exposed Construction Workers - Linn et al. (1993) estimated the inhalation rates of 19 construction workers who perform heavy outdoor labor before and during a typical work shift. The workers (laborers, iron workers, and carpenters) were employed at a site on a hospital campus in suburban Los Angeles. The construction site included a new hospital building and a separate medical office complex. The study was conducted between mid-July and early November, 1991. During this period, ozone (O_3) levels were typically high. Initially, each subject was calibrated with a 25-minute exercise test that included slow walking, fast walking, jogging, lifting, and carrying. All calibration tests were conducted in the mornings. VR

Table 5-6. Summary of Average Inhalation Rates (m^3/hr) by Age Group and Activity Levels for Laboratory Protocols

Age Group	Resting[a]	Sedentary[b]	Light[c]	Moderate[d]	Heavy[e]
Young Children[f]	0.37	0.40	0.65	DNP[g]	DNP
Children[h]	0.45	0.47	0.95	1.74	2.23
Adult Females[i]	0.43	0.48	1.33	2.76	2.96[j]
Adult Males[k]	0.54	0.60	1.45	1.93	3.63

[a] Resting defined as lying (see Appendix Table 5A-1 for original data).
[b] Sedentary defined as sitting and standing (see Appendix Table 5A-1 for original data).
[c] Light defined as walking at speed level 1.5 - 3.0 mph (see Appendix Table 5A-1 for original data).
[d] Moderate defined as fast walking (3.3 - 4.0 mph) and slow running (3.5 - 4.0 mph) (see Appendix Table 5A-1 for original data).
[e] Heavy defined as fast running (4.5 - 6.0 mph) (see Appendix Table 5A-1 for original data).
[f] Young children (both genders) 3 - 5.9 yrs old.
[g] DNP. Group did not perform this protocol or N was too small for appropriate mean comparisons. All young children did not run.
[h] Children (both genders) 6 - 12.9 yrs old.
[i] Adult females defined as adolescent, young to middle aged, and older adult females.
[j] Older adults not included in mean value since they did not perform running protocols at particular speeds.
[k] Adult males defined as adolescent, young to middle aged, and older adult males.
Source: Adapted from Adams, 1993.

Table 5-7. Summary of Average Inhalation Rates (m^3/hr) by Age Group and Activity Levels in Field Protocols

Age Group	Light[a]	Sedentary[b]	Moderate[c]

Young Children[d]	DNP[e]	DNP	0.68
Children[f]	DNP	DNP	1.07
Adult Females[g]	1.10[h]	0.51	DNP
Adult Males[i]	1.40	0.62	1.78[j]

[a] Light activity was defined as car maintenance (males), housework (females), and yard work (females) (see Appendix Table 5A-2 for original data).
[b] Sedentary activity was defined as car driving and riding (both genders) (see Appendix Table 5A-2 for original data).
[c] Moderate activity was defined as mowing (males); wood working (males); yard work (males); and play (children) (see Appendix Table 5A-2 for original data).
[d] Young children (both genders) = 3 - 5.9 yrs old.
[e] DNP. Group did not perform this protocol or N was too small for appropriate mean comparisons.
[f] Children (both genders) = 6 - 12.9 yrs old.
[g] Adult females defined as adolescent, young to middle aged, and older adult females.
[h] Older adults not included in mean value since they did not perform this activity.
[i] Adult males defined as adolescent, young to middle aged, and older adult males.
[j] Adolescents not included in mean value since they did not perform this activity.
Source: Adams, 1993.

and HR were measured simultaneously during the test. The data were analyzed using least squares regression to derive an equation for predicting VR at a given HR. Following the calibration tests, each subject recorded the type of activities to be performed during their work shift (i.e., sitting/standing, walking, lifting/carrying, and "working at trade" - defined as tasks specific to the individual's job classification). Location, and self-estimated breathing rates ("slow" similar to slow walking, "medium" similar to fast walking, and "fast" similar to running) were also recorded in the diary. During work, an investigator recorded the diary information dictated by the subjects. HR was recorded minute by minute for each subject before work and during the entire work shift. Thus, VR ranges for each breathing rate and activity category were estimated from the HR recordings by employing the relationship between VR and HR obtained from the calibration tests.

A total of 182 hours of HR recordings were obtained during the survey from the 19 volunteers; 144 hours reflected actual working time according to the diary records. The lowest actual working hours recorded was 6.6 hours and the highest recorded for a complete work shift was 11.6 hours (Linn et al., 1993). Summary statistics for predicted VR distributions for all subjects, and for job or site defined subgroups are presented in Table 5-8. The data reflect all recordings before and during work, and at break times. For all subjects, the mean IR was 1.68 m^3/hr with a standard deviation of ±0.72 (Table 5-8). Also, for most subjects, the 1st and 99th percentiles of HR were outside of the calibration range (calibration ranges are presented in Appendix Table 5A-3). Therefore, corresponding IR percentiles were extrapolated using the calibration data (Linn et al., 1993).

The data presented in Table 5-9 represent distribution patterns of IR for each subject, total subjects, and job or site defined subgroups by self-estimated breathing rates (slow, medium, fast) or by type of job activity. All data include working and non-working hours. The mean inhalation rates for most individuals showed statistically significant increases with higher self-estimated breathing rates or with increasingly strenuous job activity (Linn et al., 1993). Inhalation rates were higher in hospital site workers when compared with office site workers (Table 5-9). In spite of their higher predicted VR workers at the hospital site reported a higher percentage of slow breathing time (31 percent) than workers at the office site (20 percent), and a lower percentage of fast breathing time, 3 percent and 5 percent, respectively (Linn et al., 1993). Therefore, individuals whose work was objectively heavier than average (from VR predictions) tended to describe their work as lighter than average (Linn et al., 1993). Linn et al. (1993) also concluded that during an O_3 pollution episode, construction workers should experience similar microenvironmental O_3 exposure concentrations as other healthy outdoor workers, but with approximately twice as high a VR. Therefore, the inhaled dose of O_3 should be almost two times higher for typical heavy-construction workers than for typical healthy adults performing less strenuous outdoor jobs.

A limitation associated with this study is the small sample size. Another limitation of this study is that calibration data were not obtained at extreme conditions.

Table 5-8. Distributions of Individual and Group Inhalation/Ventilation Rate for Outdoor Workers

		Ventilation Rate (VR) (m^3/hr)		
		Percentile		
Population Group and Subgroup[a]	Mean ± SD	1	50	99
All Subjects (n[b] = 19)	1.68 ± 0.72	0.66	1.62	3.90
Job				
GCW[c]/Laborers (n=5)	1.44 ± 0.66	0.48	1.32	3.66
Iron Workers (n=3)	1.62 ± 0.66	0.60	1.56	3.24
Carpenters (n=11)	1.86 ± 0.78	0.78	1.74	4.14
Site				
Medical Office Site (n=7)	1.38 ± 0.66	0.60	1.20	3.72
Hospital Site (n=12)	1.86 ± 0.78	0.72	1.80	3.96

[a] Each group or subgroup mean was calculated from individual means, not from pooled data.
[b] n = number of individuals performing specific jobs or number of individuals at survey sites.
[c] GCW - general construction worker.

Source: Linn et al., 1993.

Table 5-9. Individual Mean Inhalation Rate (m^3/hr) by Self-Estimated Breathing Rate or Job Activity Category for Outdoor Workers

	Self-Estimated Breathing Rate (m^3/hr)			Job Activity Category (m^3/hr)			
Population Group and Subgroup	Slow	Med	Fast	Sit/Std	Walk	Carry	Trade[b]
All Subjects (n=19)	1.44	1.86	2.04	1.56	1.80	2.10	1.92
Job							
GCW[a]/Laborers (n=5)	1.20	1.56	1.68	1.26	1.44	1.74	1.56
Iron Workers (n=3)	1.38	1.86	2.10	1.62	1.74	1.98	1.92
Carpenters (n=11)	1.62	2.04	2.28	1.62	1.92	2.28	2.04
Site							
Office Site (n=7)	1.14	1.44	1.62	1.14	1.38	1.68	1.44
Hospital Site (n=12)	1.62	2.16	2.40	1.80	2.04	2.34	2.16

[a] GCW - general construction worker
[b] Trade - "Working at Trade" (i.e., tasks specific to the individual's job classification)
Source: Linn et al., 1993

Therefore, it was necessary to predict IR values that were outside the calibration range. This may introduce an unknown amount of uncertainty to the data set. Subjective self-estimated breathing rates may be another source of uncertainty in the inhalation rates estimated. An advantage is that this study provides empirical data useful in exposure assessments for a subpopulation thought to be the most highly exposed common occupational group (outdoor workers).

Layton (1993) - Metabolically Consistent Breathing Rates for Use in Dose Assessments - Layton (1993) presented a new method for estimating metabolically consistent inhalation rates for use in quantitative dose assessments of airborne radionuclides. Generally, the approach for estimating the breathing rate for a specified time frame was to calculate a time-weighted-average of ventilation rates associated with physical activities of varying durations (Layton, 1993). However, in this study, breathing rates were calculated based on oxygen consumption associated with energy expenditures for short (hours) and long (weeks and months) periods of time, using the following general equation to calculate energy-dependent inhalation rates:

$$V_E = E \times H \times VQ \qquad \text{(Eqn. 5-3)}$$

where:

- V_E = ventilation rate (L/min or m^3/hr);
- E = energy expenditure rate; [kilojoules/minute (KJ/min) or megajoules/hour (MJ/hr)];
- H = volume of oxygen [at standard temperature and pressure, dry air (STPD) consumed in the production of 1 kilojoule (KJ) of energy expended (L/KJ or m^3/MJ)]; and
- VQ = ventilatory equivalent (ratio of minute volume (L/min) to oxygen uptake (L/min)) unitless.

Three alternative approaches were used to estimate daily chronic (long term) inhalation rates for different age/gender cohorts of the U.S. population using this methodology.

First Approach

Inhalation rates were estimated by multiplying average daily food energy intakes for different age/gender cohorts, volume of oxygen (H), and ventilatory equivalent (VQ), as shown in the equation above. The average food energy intake data (Table 5-10) are based on approximately 30,000 individuals and were obtained from the USDA 1977-78 Nationwide Food Consumption Survey (USDA-NFCS). The food energy intakes were adjusted upwards by a constant factor of 1.2 for all individuals 9 years and older (Layton, 1993). This factor compensated for a consistent bias in USDA-NFCS attributed to under reporting of the foods consumed or the methods used to ascertain dietary intakes. Layton (1993) used a weighted average oxygen uptake of 0.05 L O_2/KJ which was determined from data reported in the 1977-78 USDA-NFCS and the second National Health and Nutrition Examination Survey (NHANES II). The survey sample for NHANES II was approximately 20,000 participants. The ventilatory equivalent (VQ) of 27 used was calculated as the geometric mean of VQ data that were obtained from several studies by Layton (1993).

The inhalation rate estimation techniques are shown in footnote (a) of Table 5-11. Table 5-11 presents the daily inhalation rate for each age/gender cohort. The highest daily inhalation rates were reported for children between the ages of 6-8 years (10 m^3/day), for males between 15-18 years (17 m^3/day), and females between 9-11 years (13 m^3/day). Estimated average lifetime inhalation rates for males and females are 14 m^3/day and 10^3 m /day, respectively (Table 5-11). Inhalation rates were also calculated for active and inactive periods for the various age/gender cohorts.

The inhalation rate for inactive periods was estimated by multiplying the basal metabolic rate (BMR) times the oxygen uptake (H) times the VQ. BMR was defined as "the minimum amount of energy required to support basic cellular respiration while at rest and not actively digesting food"(Layton, 1993). The inhalation rate for active periods was calculated by multiplying the inactive inhalation rate by the ratio of the rate of energy expenditure during active hours to the estimated BMR. This ratio is presented as F in Table 5-11. These data for active and inactive inhalation rates are also presented in Table 5-11. For children, inactive and active inhalation rates ranged between 2.35 and 5.95 m^3/day and 6.35 to 13.09 m^3/day, respectively. For adult males (19-64 years old), the average inactive and active inhalation rates were approximately 10 and 19 m^3/day, respectively. Also, the average inactive and active inhalation rates for adult females (19-64 years old) were approximately 8 and 12 m^3/day, respectively.

Second Approach

Inhalation rates were calculated by multiplying the BMR of the population cohorts times A (ratio of total daily energy expenditure to daily BMR) times H times VQ. The BMR data obtained from literature were statistically analyzed and regression equations were developed to predict BMR from body weights of various age/gender cohorts (Layton, 1993). The statistical data used to develop the regression equations are presented in Appendix Table 5A-4. The data obtained from the second

Table 5-10. Comparisons of Estimated Basal Metabolic Rates (BMR) with Average Food-Energy Intakes for Individuals Sampled in the 1977-78 NFCS

Cohort/Age (years)	Body Weight kg	BMR[a] MJ d^{-1}[b]	BMR[a] kcal d^{-1}[c]	Energy Intake (EFD) MJ d^{-1}	Energy Intake (EFD) kcal d^{-1}	Ratio EFD/BMR
Children						
Under 1	7.6	1.74	416	3.32	793	1.90
1 to 2	13	3.08	734	5.07	1209	1.65
3 to 5	18	3.69	881	6.14	1466	1.66
6 to 8	26	4.41	1053	7.43	1774	1.68
Males						
9 to 11	36	5.42	1293	8.55	2040	1.58
12 to 14	50	6.45	1540	9.54	2276	1.48
15 to 18	66	7.64	1823	10.8	2568	1.41
19 to 22	74	7.56	1804	10.0	2395	1.33
23 to 34	79	7.87	1879	10.1	2418	1.29
35 to 50	82	7.59	1811	9.51	2270	1.25
51 to 64	80	7.49	1788	9.04	2158	1.21
65 to 74	76	6.18	1476	8.02	1913	1.30
75 +	71	5.94	1417	7.82	1866	1.32
Females						
9 to 11	36	4.91	1173	7.75	1849	1.58
12 to 14	49	5.64	1347	7.72	1842	1.37
15 to 18	56	6.03	1440	7.32	1748	1.21
19 to 22	59	5.69	1359	6.71	1601	1.18
23 to 34	62	5.88	1403	6.72	1603	1.14
35 to 50	66	5.78	1380	6.34	1514	1.10
51 to 64	67	5.82	1388	6.40	1528	1.10
65 to 74	66	5.26	1256	5.99	1430	1.14
75 +	62	5.11	1220	5.94	1417	1.16

[a] Calculated from the appropriate age and gender-based BMR equations given in Appendix Table 5A-4.
[b] MJ d^{-1} - mega joules/day
[c] kcal d^{-1} - kilo calories/day
Source: Layton, 1993.

Table 5-11. Daily Inhalation Rates Calculated from Food-Energy Intakes

Cohort/Age (years)	L[d]	Daily Inhalation Rate[a] (m³/day)	Sleep (h)	MET[b] Value A[e]	MET[b] Value F[f]	Inhalation Rates Inactive[c] (m³/day)	Inhalation Rates Active[c] (m³/day)
Children							
<1	1	4.5	11	1.9	2.7	2.35	6.35
1 - 2	2	6.8	11	1.6	2.2	4.16	9.15
3 - 5	3	8.3	10	1.7	2.2	4.98	10.96
6 - 8	3	10	10	1.7	2.2	5.95	13.09
Males							
9 - 11	3	14	9	1.9	2.5	7.32	18.3
12 - 14	3	15	9	1.8	2.2	8.71	19.16
15 - 18	4	17	8	1.7	2.1	10.31	21.65
19 - 22	4	16	8	1.6	1.9	10.21	19.4
23 - 34	11	16	8	1.5	1.8	10.62	19.12
35 - 50	16	15	8	1.5	1.8	10.25	18.45
51 - 64	14	15	8	1.4	1.7	10.11	17.19
65 - 74	10	13	8	1.6	1.8	8.34	15.01
75+	1	13	8	1.6	1.9	8.02	15.24
Lifetime average [g]		14					
Females							
9 - 11	3	13	9	1.9	2.5	6.63	16.58
12 - 14	3	12	9	1.6	2.0	7.61	15.20
15 - 18	4	12	8	1.5	1.7	8.14	13.84
19 - 22	4	11	8	1.4	1.6	7.68	12.29
23 - 34	11	11	8	1.4	1.6	7.94	12.7
35 - 50	16	10	8	1.3	1.5	7.80	11.7
51 - 64	14	10	8	1.3	1.5	7.86	11.8
65 - 74	10	9.7	8	1.4	1.5	7.10	10.65
75+	1	9.6	8	1.4	1.6	6.90	11.04
Lifetime average [g]		10					

[a] Daily inhalation rate was calculated by multiplying the EFD values (see Table 5-10) by H x VQ x (m^3 1,000 L^{-1}) for subjects under 9 years of age and by 1.2 x H x VQ x (m^3 1,000 L^{-1}) (for subjects 9 years of age and older (see text for explanation).
Where:
EFD = Food energy intake (Kcal/day) or (MJ/day)
H = Oxygen uptake = 0.05 LO_2/KJ or 0.21 LO_2/Kcal
VQ = Ventilation equivalent = 27 = geometric mean of VQs (unitless)

[b] MET = Metabolic equivalent

[c] Inhalation rate for inactive periods was calculated as BMR x H x VQ x (d 1,440 min^{-1}) and for active periods by multiplying inactive inhalation rate by F (See footnote f); BMR values are from Table 5-10.
Where:
BMR = Basal metabolic rate (MJ/day) or (kg/hr)

[d] L is the number of years for each age cohort.

[e] For individuals 9 years of age and older, A was calculated by multiplying the ratio for EFD/BMR (unitless) (Table 5-10) by the factor 1.2 (see text for explanation).

[f] F = (24A - S)/(24 - S) (unitless), ratio of the rate of energy expenditure during active hours to the estimated BMR (unitless)
Where:
S = Number of hours spent sleeping each day (hrs)

[g] Lifetime average was calculated by multiplying individual inhalation rate by corresponding L values summing the products across cohorts and dividing the result by 75, the total of the cohort age spans.

Source: Layton, 1993.

approach are presented in Table 5-12. Inhalation rates for children (6 months - 10 years) ranged from 7.3-9.3 m^3/day for male and 5.6 to 8.6 m^3/day for female children and (10-18 years) was 15 m^3/day for males and 12 m^3/day for females. Adult females (18 years and older) ranged from 9.9-11 m^3/day and adult males (18 years and older) ranged from 13-17 m^3/day. These rates are similar to the daily inhalation rates obtained using the first approach. Also, the inactive inhalation rates obtained from the first approach are lower than the inhalation rates obtained using the second approach. This may be attributed to the BMR multiplier employed in the equation of the second approach to calculate inhalation rates.

Third Approach

Inhalation rates were calculated by multiplying estimated energy expenditures associated with different levels of physical activity engaged in over the course of an average day by VQ and H for each age/gender cohort. The energy expenditure associated with each level of activity was estimated by multiplying BMRs of each activity level by the metabolic equivalent (MET) and by the time spent per day performing each activity for each age/gender population. The time-activity data used in this approach were obtained from a survey conducted by Sallis et al. (1985) (Layton, 1993). In that survey, the physical-activity categories and associated MET values used were sleep, MET=1; light-activity, MET=1.5; moderate activity, MET=4; hard activity, MET=6; and very hard activity, MET=10. The physical activities were based on recall by the test subject (Layton, 1993). The survey sample was 2,126 individuals (1,120 women and 1,006 men) ages 20-74 years that were randomly selected from four communities in California. The BMRs were estimated using the metabolic equations presented in Appendix Table 5A-4. The body weights were obtained from a study conducted by Najjar and Rowland (1987) which randomly sampled individuals from the U.S. population (Layton, 1993). Table 5-13 presents the inhalation rates (V_E) in m^3/day and m^3/hr for adult males and females aged 20-74 years at five physical activity levels. The total daily inhalation rates ranged from 13-17 m^3/day for adult males and 11-15 m^3/day for adult females.

The rates for adult females were higher when compared with the other two approaches. Layton (1993) reported that the estimated inhalation rates obtained from the third approach were particularly sensitive to the MET value that represented the energy expenditures for light activities. Layton (1993) stated further that in the original time-activity survey (i.e., conducted by Sallis et al., 1985), time spent performing light activities was not presented. Therefore, the time spent at light activities was estimated

Table 5-12. Daily Inhalation Rates Obtained from the Ratios of Total Energy Expenditure to Basal Metabolic Rate (BMR)

Gender/Age (yrs)	Body Weight[a] (kg)	BMR[b] (MJ/day)	VQ	A[c]	H (m^3O_2/MJ)	Inhalation Rate, V_E (m^3/day)[d]
Male						
0.5 - <3	14	3.4	27	1.6	0.05	7.3
3 - <10	23	4.3	27	1.6	0.05	9.3
10 - <18	53	6.7	27	1.7	0.05	15
18 - <30	76	7.7	27	1.59	0.05	17
30 - <60	80	7.5	27	1.59	0.05	16
60+	75	6.1	27	1.59	0.05	13
Female						
0.5 - <3	11	2.6	27	1.6	0.05	5.6
3 - <10	23	4.0	27	1.6	0.05	8.6
10 - <18	50	5.7	27	1.5	0.05	12
18 - <30	62	5.9	27	1.38	0.05	11
30 - <60	68	5.8	27	1.38	0.05	11
60+	67	5.3	27	1.38	0.05	9.9

[a] Body weight was based on the average weights for age/gender cohorts in the U.S. population.
[b] The BMRs (basal metabolic rate) are calculated using the respective body weights and BMR equations (see Appendix Table 5A-4).
[c] The values of the BMR multiplier (EFD/BMR) for those 18 years and older were derived from the Basiotis et al. (1989) study: Male = 1.59, Female = 1.38. For males and females under 10 years old, the mean BMR multiplier used was 1.6. For males and females aged 10 to < 18 years, the mean values for A given in Table 5-11 for 12-14 years and 15-18 years, age brackets for males and females were used: male = 1.7 and female = 1.5.
[d] Inhalation rate = BMR x A x H x VQ; VQ = ventilation equivalent and H = oxygen uptake.
Source: Layton, 1993.

Table 5-13. Daily Inhalation Rates Based on Time-Activity Survey

Age (yrs) and Activity	MET	Males						Females					
		Body Weight[a] (kg)	BMR[b] (KJ/hr)	Duration[c] (hr/day)	E[d] (MJ/day)	V_E[e] (m^3/day)	V_E[f] (m^3/hr)	Body Weight[a] (kg)	BMR[b] (KJ/hr)	Duration[c] (hr/day)	E[d] (MJ/day)	V_E[e] (m^3/day)	V_E[f] (m^3/hr)
20-34													
Sleep	1	76	320	7.2	2.3	3.1	0.4	62	283	7.2	2.0	2.8	0.4
Light	1.5	76	320	14.5	7.0	9.4	0.7	62	283	14.5	6.2	8.3	0.6
Moderate	4	76	320	1.2	1.5	2.1	1.7	62	283	1.2	1.4	1.8	1.5
Hard	6	76	320	0.64	1.2	1.7	2.6	62	283	0.64	1.1	1.5	2.3
Very Hard	10	76	320	0.23	0.74	1.0	4.3	62	283	0.23	0.65	0.88	3.8
Totals				24	17	17				24	11	15	
35-49													
Sleep	1	81	314	7.1	2.2	3.0	0.4	67	242	7.1	1.7	2.3	0.3
Light	1.5	81	314	14.6	6.9	9.3	0.6	67	242	14.6	5.3	7.2	0.5
Moderate	4	81	314	1.4	1.8	2.4	1.7	67	242	1.4	1.4	1.8	1.3
Hard	6	81	314	0.59	1.1	1.5	2.5	67	242	0.59	0.9	1.2	2.0
Very Hard	10	81	314	0.29	0.91	1.2	4.2	67	242	0.29	0.70	0.95	3.2
Totals				24	13	17				24	9.9	13	
50-64													
Sleep	1	80	312	7.3	2.3	3.1	0.4	68	244	7.3	1.8	2.4	0.3
Light	1.5	80	312	14.9	7.0	9.4	0.6	68	244	14.9	5.4	7.4	0.5
Moderate	4	80	312	1.1	1.4	1.9	1.7	68	244	1.1	1.1	1.4	1.3
Hard	6	80	312	0.50	0.94	1.3	2.5	68	244	0.5	0.7	1.0	2.0
Very Hard	10	80	312	0.14	0.44	0.6	4.2	68	244	0.14	0.34	0.46	3.3
Totals				24	12	16				24	9.4	13	
65-74													
Sleep	1	75	256	7.3	1.9	2.5	0.3	67	221	7.3	1.6	2.2	0.3
Light	1.5	75	256	14.9	5.7	7.7	0.5	67	221	14.9	4.9	6.7	0.4
Moderate	4	75	256	1.1	1.1	1.5	1.4	67	221	1.1	1.0	1.3	1.2
Hard	6	75	256	0.5	0.8	1.0	2.1	67	221	0.5	0.7	0.9	1.8
Very Hard	10	75	256	0.14	0.36	0.48	3.5	67	221	0.14	0.31	0.42	3.0
Totals				24	9.8	13				24	8.5	11	

[a] Body weights were obtained from Najjar and Rowland (1987)
[b] The basal metabolic rates (BMRs) for the age/gender cohorts were calculated using the respective body weights and the BMR equations (Appendix Table 5A-4)
[c] Duration of activities were obtained from Sallis et al. (1985)
[d] Energy expenditure rate (E) was calculated by multiplying BMR (KJ/hr) x (MJ/1000 KJ) x duration (hr/day) x MET
[e] V_E (inhalation rate) was calculated by multiplying E (MJ/day) by H(0.05 m^3 oxygen/MJ) by VQ (27)
[f] V_E (m^3/hr) was calculated by multiplying BMR (KJ/hr) x (MJ/1000 KJ) x MET x H (0.05 m^3 oxygen/MJ) x VQ (27)

Source: Layton, 1993.

by subtracting the total time spent at sleep, moderate, heavy, and very heavy activities from 24 hours (Layton, 1993). The range of inhalation rates for adult females were 9.6 to 11 m^3/day, 9.9 to 11 m^3/day, and 11 to 15 m^3/day, for the first, second, and third approach, respectively. The inhalation rates for adult males ranged from 13 to 16 m^3/day for the first approach, and 13 to 17 m^3/day for the second and third approaches.

Inhalation rates were also obtained for short-term exposures for various age/gender cohorts and five energy-expenditure categories (rest, sedentary, light, moderate, and heavy). BMRs were multiplied by the product of MET, H, and VQ. The data obtained for short term exposures are presented in Table 5-14.

The major strengths of the Layton (1993) study are that it obtains similar results using three different approaches to estimate inhalation rates in different age groups and that the populations are large, consisting of men, women, and children. Explanations for differences in results due to metabolic measurements, reported diet, or activity patterns are supported by observations reported by other investigators in other studies. Major limitations of this study are that activity pattern levels estimated in this study are somewhat subjective, the explanation that activity pattern differences is responsible for the lower level obtained with the metabolic approach (25 percent) compared to the activity pattern approach is not well supported by the data, and different populations were used in each approach which may introduce error.

5.2.3. Relevant Inhalation Rate Studies

International Commission on Radiological Protection (ICRP) (1981) - Report of the Task Group on Reference Man - The International Commission of Radiological Protection (ICRP) estimated daily inhalation rates for reference adult males, adult females, children (10 years old), infant (1 year old), and newborn babies by using a time-activity-ventilation approach. This approach for estimating inhalation rate over a specified period of time was based on calculating a time weighted average of inhalation rates associated with physical activities of varying durations. ICRP (1981) compiled reference values (Appendix Table 5A-5) of minute volume/inhalation rates from various literature sources. ICRP (1981) assumed that the daily activities of a reference man and woman, and child (10 yrs) consisted of

Table 5-14. Inhalation Rates for Short-Term Exposures

Gender/Age (yrs)	Weight (kg)[a]	BMR[b] (MJ/day)	Rest	Sedentary	Light	Moderate	Heavy
			MET (BMR Multiplier)				
			1	1.2	2[c]	4[d]	10[e]
			Inhalation Rate (m^3/hr)[f,g]				
Male							
0.5 - <3	14	3.40	0.19	0.23	0.38	0.78	1.92
3 - <10	23	4.30	0.24	0.29	0.49	0.96	2.40
10 - <18	53	6.70	0.38	0.45	0.78	1.50	3.78
18 - <30	76	7.70	0.43	0.52	0.84	1.74	4.32
30 - <60	80	7.50	0.42	0.50	0.84	1.68	4.20
60+	75	6.10	0.34	0.41	0.66	1.38	3.42
Female							
0.5 - <3	11	2.60	0.14	0.17	0.29	0.60	1.44
3 - <10	23	4.00	0.23	0.27	0.45	0.90	2.28
10 - <18	50	5.70	0.32	0.38	0.66	1.26	3.18
18 - <30	62	5.90	0.33	0.40	0.66	1.32	3.30
30 - <60	68	5.80	0.32	0.39	0.66	1.32	3.24
60+	67	5.30	0.30	0.36	0.59	1.20	3.00

[a] Body weights were based on average weights for age/gender cohorts of the U.S. population
[b] The BMRs for the age/gender cohorts were calculated using the respective body weights and the BMR equations (Appendix Table 5A-4).
[c] Range of 1.5 - 2.5.
[d] Range of 3 - 5.
[e] Range of >5 - 20.
[f] The inhalation rate was calculated by multiplying BMR (MJ/day) x H (0.05 L/KJ) x MET x VQ (27) x (d/1,440 min)
[g] Original data were presented in L/min. Conversion to m^3/hr was obtained as follows:

$$\frac{60\ \text{min}}{\text{hr}} \times \frac{m^3}{1000\text{L}} \times \frac{\text{L}}{\text{min}}$$

Source: Layton, 1993.

8 hours of rest and 16 hours of light activities. It was also assumed that 16 hours were divided evenly between occupational and nonoccupational activities. It was assumed that a day consisted of 14 hours resting and 10 hours light activity for an infant (1 yr). A newborn's daily activities consisted of 23 hours resting and 1 hour light activity. Table 5-15 presents the daily inhalation rates obtained for all ages/genders. The estimated inhalation rates were 22.8 m^3/day for adult males, 21.1 m^3/day for adult females, 14.8 m^3/day for children (age 10 years), 3.76 m^3/day for infants (age 1 year), and 0.78 m^3/day for newborns.

Table 5-15. Daily Inhalation Rates Estimated From Daily Activities[a]

Subject	Inhalation Rate (IR) Resting (m^3/hr)	Light Activity (m^3/hr)	Daily Inhalation Rate (DIR)[b] (m^3/day)
Adult Man	0.45	1.2	22.8
Adult Woman	0.36	1.14	21.1
Child (10 yrs)	0.29	0.78	14.8
Infant (1 yr)	0.09	0.25	3.76
Newborn	0.03	0.09	0.78

[a] Assumptions made were based on 8 hours resting and 16 hours light activity for adults and children (10 yrs); 14 hours resting and 10 hours light activity for infants (1 yr); 23 hours resting and 1 hour light activity for newborns.

[b] $$DIR = \frac{1}{T} \sum_{i=1}^{K} IR_i t_i$$

IR_i = Corresponding inhalation rate at ith activity
t_i = Hours spent during the ith activity
k = Number of activity periods
T = Total time of the exposure period (i.e., a day)

Source: ICRP, 1981

A limitation associated with this study is that the validity and accuracy of the inhalation rates data used in the compilation were not specified. This may introduce some degree of uncertainty in the results obtained. Also, the approach used involved assuming hours spent by various age/gender cohorts in specific activities. These assumptions may over/under-estimate the inhalation rates obtained.

U.S. EPA (1985) - Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments - Due to a paucity of information in the literature regarding equations used to develop statistical distributions of minute ventilation/ventilation rate at all activity levels for male and female children and adults, the U.S. EPA (1985) compiled measured values of minute ventilation for various age/gender cohorts from early studies. In more recent investigations, minute ventilations have been measured more as background information than as research objective itself and the available studies have been for specific subpopulations such as obese, asthmatics, or marathon runners. The data compiled by the U.S. EPA (1985) for each age/gender cohorts were obtained at various activity levels. These levels were categorized as light, moderate, or heavy according to the criteria developed by the EPA Office of Environmental Criteria and Assessment for the Ozone Criteria Document. These criteria were developed for a reference male adult with a body weight of 70 kg (U.S. EPA, 1985). The minute ventilation rates for adult males based on these activity level categories are detailed in Appendix Table 5A-6.

Table 5-16 presents a summary of inhalation rates by age, gender, and activity level (detailed data are presented in Appendix Table 5A-7). A description of activities included in each activity level is also presented in Table 5-16. Table 5-16 indicates that at rest, the average adult inhalation rate is 0.5 m^3/hr. The mean inhalation rate for children at rest, ages 6 and 10 years, is 0.4 m^3/hr. Table 5-17 presents activity pattern data aggregated for three microenvironments by activity level for all age groups. The total average hours spent indoors was 20.4, outdoors was 1.77, and in transportation vehicle was 1.77. Based on the data presented in Tables 5-16 and 5-17, a daily inhalation rate was calculated for adults and children by using a time-activity-ventilation approach. These data are presented in Table 5-18. The calculated average daily inhalation rate is 16 m^3/day for adults. The average daily inhalation rate for children (6 and 10 yrs) is 18.9 m^3/day ([16.74 + 21.02]/2).

A limitation associated with this study is that many of the values used in the data compilation were from early studies. The accuracy and/or validity of the values used and data collection method were not presented in U.S. EPA (1985). This introduces uncertainty in the results obtained. An advantage of this study is that the data are actual measurement data for a large number of subjects and the data are presented for both adults and children.

Shamoo et al. (1990) - Improved Quantitation of Air Pollution Dose Rates by Improved Estimation of Ventilation Rate- Shamoo et al. (1990) conducted this study to develop and validate new methods to accurately estimate ventilation rates for typical individuals during their normal activities. Two practical approaches were tested for estimating ventilation rates indirectly: (1) volunteers were trained to estimate their own VR at

Table 5-16. Summary of Human Inhalation Rates for Men, Women, and Children by Activity Level (m^3/hour)[a]

	n[b]	Resting[c]	n	Light[d]	n	Moderate[e]	n	Heavy[f]
Adult male	454	0.7	102	0.8	102	2.5	267	4.8
Adult female	595	0.3	786	0.5	106	1.6	211	2.9
Average adult[g]		0.5		0.6		2.1		3.9
Child, age 6 years	8	0.4	16	0.8	4	2.0	5	2.3
Child, age 10 years	10	0.4	40	1.0	29	3.2	43	3.9

[a] Values of inhalation rates for males, females, and children (male and female) presented in this table represent the mean of values reported for each activity level in 1985. (See Appendix Table 5A-7 for a detailed listing of the data from U.S. EPA, 1985.)
[b] n = number of observations at each activity level.
[c] Includes watching television, reading, and sleeping.
[d] Includes most domestic work, attending to personal needs and care, hobbies, and conducting minor indoor repairs and home improvements.
[e] Includes heavy indoor cleanup, performance of major indoor repairs and alterations, and climbing stairs.
[f] Includes vigorous physical exercise and climbing stairs carrying a load.
[g] Derived by taking the mean of the adult male and adult female values for each activity level.

Source: Adapted from U.S. EPA, 1985.

Table 5-17. Activity Pattern Data Aggregated for Three Microenvironments by Activity Level for all Age Groups

Microenvironment	Activity Level	Average Hours Per Day in Each Microenvironment at Each Activity Level
Indoors	Resting	9.82
	Light	9.82
	Moderate	0.71
	Heavy	0.098
	TOTAL	20.4
Outdoors	Resting	0.505
	Light	0.505
	Moderate	0.65
	Heavy	0.12
	TOTAL	1.77
In Transportation Vehicle	Resting	0.86
	Light	0.86
	Moderate	0.05
	Heavy	0.0012
	TOTAL	1.77

Source: Adapted from U.S. EPA, 1985.

Table 5-18. Summary of Daily Inhalation Rates Grouped by Age and Activity level

Subject	Daily Inhalation Rate (m^3/day)[a]				Total Daily IR[b] (m^3/day)
	Resting	Light	Moderate	Heavy	
Adult Male	7.83	8.95	3.53	1.05	21.4
Adult Female	3.35	5.59	2.26	0.64	11.8
Adult Average[c]	5.60	6.71	2.96	0.85	16
Child (age 6)	4.47	8.95	2.82	0.50	16.74
Child (age 10)	4.47	11.19	4.51	0.85	21.02

[a] Daily inhalation rate was calculated using the following equation:

$$IR = \frac{1}{T}\sum_{i=1}^{K} IR_i t_i$$

IR_i = inhalation rate at i^{th} activity (Table 5-18)
t_i = hours spent per day during i^{th} activity (Table 5-19)
k = number of activity periods
T = total time of the exposure period (e.g., a day)

[b] Total daily inhalation rate was calculated by summing the specific activity (resting, light, moderate, heavy) daily inhalation rate.

Source: Generated using the data from U.S. EPA (1985) as shown in Tables 5-16 and 5-17.

various controlled levels of exercise; and (2) individual VR and HR relationships were determined in another set of volunteers during supervised exercise sessions (Shamoo et al., 1990). In the first approach, the training session involved 9 volunteers (3 females and 6 males) from 21 to 37 years old. Initially the subjects were trained on a treadmill with regularly increasing speeds. VR measurements were recorded during the last minute of the 3-minute interval at each speed. VR was reported to the subjects as low (1.4 m^3/hr), medium (1.5-2.3 m^3/hr), heavy (2.4-3.8 m^3/hr), and very heavy (3.8^3 m /hr or higher) (Shamoo et al., 1990).

Following the initial test, treadmill training sessions were conducted on a different day in which 7 different speeds were presented, each for 3 minutes in arbitrary order. VR was measured and the subjects were given feedback with the four ventilation ranges provided previously. After resting, a treadmill testing session was conducted in which seven speeds were presented in different arbitrary order from the training session. VR was measured and each subject estimated their own ventilation level at each speed. The correct level was then revealed to each subject after his/her own estimate. Subsequently, two 3-hour outdoor supervised exercise sessions were conducted in the summer on two consecutive days. Each hour consisted of 15 minutes each of rest, slow walking, jogging, and fast walking. The subjects' ventilation level and VR were recorded; however, no feedback was given to the subjects. Electrocardiograms were recorded via direct connection or telemetry and HR was measured concurrently with ventilation measurement for all treadmill sessions.

The second approach consisted of two protocol phases (indoor/outdoor exercise sessions and field testing). Twenty outdoor adult workers between 19-50 years old were recruited. Indoor and outdoor supervised exercises similar to the protocols in the first approach were conducted; however, there were no feedbacks. Also, in this approach, electrocardiograms were recorded and HR was measured concurrently with VR. During the field testing phase, subjects were trained to record their activities during three different 24-hour periods during one week. These periods included their most active working and non-working days. HR was measured quasi-continuously during the 24-hour periods that activities were recorded. The subjects recorded in a diary all changes in physical activity, location, and exercise levels during waking hours. Self-estimated activities in supervised exercises and field studies were categorized as slow (resting, slow walking or equivalent), medium (fast walking or equivalent), and fast (jogging or equivalent).

Inhalation rates were not presented in this study. In the first approach, about 68 percent of all self-estimates were correct for the 9 subjects sampled (Shamoo et al., 1990). Inaccurate self-estimates occurred in the younger male population who were highly physically fit and were competitive aerobic trainers. This subset of sample population tended to underestimate their own physical activity levels at higher VR ranges. Shamoo et al. (1990) attributed this to a "macho effect." In the second approach, a regression analysis was conducted that related the logarithm of VR to HR. The logarithm of VR correlated better with HR than VR itself (Shamoo et al., 1990).

A limitation associated with this study is that the population sampled is not representative of the general U.S. population. Also, ventilation rates were not presented. Training individuals to estimate their VR may contribute to uncertainty in the results because the estimates are subjective. Another limitation is that calibration data were not obtained at extreme conditions; therefore, the VR/HR relationship obtained may be biased. An additional limitation is that training subjects may be too labor-intensive for widespread use in exposure assessment studies. An advantage of this study is that HR recordings are useful in predicting ventilation rates which in turn are useful in estimating exposure.

Shamoo et al. (1991) - Activity Patterns in a Panel of Outdoor Workers Exposed to Oxidant Pollution - Shamoo et al. (1991) investigated summer activity patterns in 20 adult volunteers with potentially high exposure to ambient oxidant pollution. The selected volunteer subjects were 15 men and 5 women ages 19-50 years from the Los Angeles area. All volunteers worked outdoors at least 10 hours per week. The experimental approach involved two stages: (1) indirect objective estimation of VR from HR measurements; and (2) self estimation of inhalation/ventilation rates recorded by subjects in diaries during their normal activities.

The approach consisted of calibrating the relationship between VR and HR for each test subject in controlled exercise; monitoring by subjects of their own normal activities with diaries and electronic HR recorders; and then relating VR with the activities described in the diaries (Shamoo et al., 1991). Calibration tests were conducted for indoor and outdoor supervised exercises to determine individual relationships between VR and HR. Indoors, each subject was tested on a treadmill at rest and at increasing speeds. HR and VR were measured at the third minute at each 3-minute interval speed. In addition, subjects were tested while walking a 90-meter course in a corridor at 3 self-selected speeds (normal, slower than normal, and faster than normal) for 3 minutes.

Two outdoor testing sessions (one hour each) were conducted for each subject, 7 days apart. Subjects exercised on a 260-meter asphalt course. A session involved 15 minutes each of rest, slow walking, jogging, and fast walking during the first hour. The sequence was also repeated during the second hour. HR and VR measurements were recorded starting at the 8th minute of each 15-minute segment. Following the calibration tests, a field study was conducted in which subject's self-monitored their activities by filling out activity diary booklets, self-estimated their breathing rates, and their HR. Breathing rates were defined as sleep, slow (slow or normal walking); medium (fast walking); and fast (running) (Shamoo et al., 1991). Changes in location, activity, or breathing rates during three 24-hr periods within a week were recorded. These periods included their most active working and non-working days. Each subject wore Heart Watches which recorded their HR once per minute during the field study. Ventilation rates were estimated for the following categories: sleep, slow, medium, and fast.

Calibration data were fit to the equation log (VR) = intercept + (slope x HR), each individual's intercept and slope were determined separately to provide a specific equation that predicts each subject's VR from measured HR (Shamoo et al., 1991). The average measured VRs were 0.48, 0.9, 1.68, and 4.02 m^3/hr for rest, slow walking or normal walking, fast walking and jogging, respectively (Shamoo et al., 1991). Collectively, the diary recordings showed that sleep occupied about 33 percent of the subject's time; slow activity 59 percent; medium activity 7 percent; and fast activity 1 percent. The diary data covered an average of 69 hours per subject (Shamoo et al., 1991). Table 5-19 presents the distribution pattern of predicted ventilation rates and equivalent ventilation rates (EVR) obtained at the four activity levels. EVR was defined as the VR per square meter of body surface area, and also as a percentage of the subjects average VR over the entire field monitoring period (Shamoo et al., 1991).

Table 5-19. Distribution Pattern of Predicted VR and EVR (equivalent ventilation rate) for 20 Outdoor Workers

		VR (m^3/hr)[a]		EVR[b] (m^3/hr/m^2 body surface)	
Self-Reported Activity Level	N[c]	Arithmetic Mean ± SD	Geometric Mean ± SD	Arithmetic Mean ± SD	Geometric Mean ± SD
Sleep	18,597	0.42 ± 0.16	0.39 ± 0.08	0.23 ± 0.08	0.22 ± 0.08
Slow	41,745	0.71 ± 0.4	0.65 ± 0.09	0.38 ± 0.20	0.35 ± 0.09
Medium	3,898	0.84 ± 0.47	0.76 ± 0.09	0.48 ± 0.24	0.44 ± 0.09
Fast	572	2.63 ± 2.16	1.87 ± 0.14	1.42 ± 1.20	1.00 ± 0.14

Percentile Rankings, VR

	1	5	10	50	90	95	99	99.9
Sleep	0.18	0.18	0.24	0.36	0.66	0.72	0.90	1.20
Slow	0.30	0.36	0.36	0.66	1.08	1.32	1.98	4.38
Medium	0.36	0.42	0.48	0.72	1.32	1.68	2.64	3.84
Fast	0.42	0.54	0.60	1.74	5.70	6.84	9.18	10.26

Percentile Rankings, EVR

	1	5	10	50	90	95	99	99.9
Sleep	0.12	0.12	0.12	0.24	0.36	0.36	0.48	0.60
Slow	0.18	0.18	0.24	0.36	0.54	0.66	1.08	2.40
Medium	0.18	0.24	0.30	0.42	0.72	0.90	1.38	2.28
Fast	0.24	0.30	0.36	0.90	3.24	3.72	4.86	5.52

[a] Data presented by Shamoo et al. (1991) in liters/minute were converted to m^3/hr.
[b] EVR = VR per square meter of body surface area.
[c] Number of minutes with valid appearing heart rate records and corresponding daily records of breathing rate.
Source: Shamoo et al., 1991

The overall mean predicted VR was 0.42 m^3/hr for sleep; 0.71 m^3/hr for slow activity; 0.84 m^3/hr for medium activity; and 2.63 m^3/hr for fast activity.

The mean predicted VR and standard deviation, and the percentage of time spent in each combination of VR, activity type (essential and non-essential), and location (indoor and outdoor) are presented in Table 5-20. Essential activities include income-related work, household chores, child care, study and other school activities, personal care and destination-oriented travel. Non-essential activities include sports and active leisure, passive leisure, some travel, and social or civic activities (Shamoo et al., 1991). Table 5-20 shows that inhalation rates were higher outdoors than indoors at slow, medium, and fast activity levels. Also, inhalation rates were higher for outdoor non-essential activities than for indoor non-essential activity levels at slow, medium, and fast self-reported breathing rates (Table 5-20).

An advantage of this study is that subjective activity diary data can provide exposure modelers with useful rough estimates of VR for groups of generally healthy people. A limitation of this study is that the results obtained show high within-person and between-person variability in VR at each diary-recorded level, indicating that VR estimates from diary reports could potentially be substantially misleading in individual cases. Another limitation of this study is that elevated HR data of slow activity at the second hour of the exercise session reflect persistent effects of exercise and/or heat stress. Therefore, predictions of VR from the VR/HR relationship may be biased.

Shamoo et al. (1992) - Effectiveness of Training Subjects to Estimate Their Level of Ventilation - Shamoo et al. (1992) conducted a study where nine non-sedentary subjects in good health were trained on a treadmill to estimate their own ventilation rates at four activity levels: low, medium, heavy, and very heavy. The purpose of the study was to train the subjects self-estimation of ventilation in the field and assess the effectiveness of the training (Shamoo et al., 1992). The subjects included 3 females and 6 males between 21 to 37 years of age. The tests were conducted in four stages. First, an initial treadmill pretest was conducted indoors at various speeds until the four ventilation levels were experienced by each subject; VR was measured and feedback was given to the subjects. Second, two treadmill training sessions which involved seven 3-minute segments of varying speeds based on initial tests were conducted; VR was measured and feedback was given to the subjects. Another similar session was conducted; however, the subjects estimated

Table 5-20. Distribution Pattern of Inhalation Rate by Location and Activity Type for 20 Outdoor Workers

Location	Activity Type[a]	Self-reported Activity Level	% of Time	Inhalation rate (m^3/hr)[b] ± SD	% of Avg.[c]
Indoor	Essential	Sleep	28.7	0.42 ± 0.12	69 ± 15
		Slow	29.5	0.72 ± 0.36	106 ± 43
		Medium	2.4	0.72 ± 0.30	129 ± 38
		Fast	0	0	0
Indoor	Non-essential	Slow	20.4	0.66 ± 0.36	98 ± 36
		Medium	0.9	0.78 ± 0.30	120 ± 50
		Fast	0.2	1.86 ± 0.96	278 ± 124
Outdoor	Essential	Slow	11.3	0.78 ± 0.36	117 ± 42
		Medium	1.8	0.84 ± 0.54	130 ± 56
		Fast	0	0	0
Outdoor	Non-essential	Slow	3.2	0.90 ± 0.66	136 ± 90
		Medium	0.8	1.26 ± 0.60	213 ± 91
		Fast	0.7	2.82 ± 2.28	362 ± 275

[a] Essential activities include income-related, work, household chores, child care, study and other school activities, personal care, and destination-oriented travel; Non-essential activities include sports and active leisure, passive leisure, some travel, and social or civic activities.
[b] Data presented by Shamoo et al. (1991) in liters/mintue were converted to m^3/hr.
[c] Statistic was calculated by converting each VR for a given subject to a percentage of her/his overall average.
Source: Adapted from Shamoo et al., (1991).

their own ventilation level during the last 20 seconds of each segment and VR was measured during the last minute of each segment. Immediate feedback was given to the subject's estimate; and the third and fourth stages involved 2 outdoor sessions of 3 hours each. Each hour comprised 15 minutes each of rest, slow walking, jogging, and fast walking. The subjects estimated their own ventilation level at the middle of each segment. The subject's estimate was verified by a respirometer which measured VR in the middle of each 15-minute activity. No feedback was given to the subject. The overall percent correct score obtained for all ventilation levels was 68 percent (Shamoo et al., 1992). Therefore, Shamoo et al. (1992) concluded that this training protocol was effective in training subjects to correctly estimate their minute ventilation levels.

For this handbook, inhalation rates were analyzed from the raw data provided by Shamoo et al. (1992). Table 5-21 presents the mean inhalation rates obtained from this analysis at four ventilation levels in two microenvironments (i.e., indoors and outdoors) for all subjects. The mean inhalation rates for all subjects were 0.93, 1.92, 3.01, 4.80 m^3/hr for low, medium, heavy, and very heavy activities, respectively.

Table 5-21. Actual Inhalation Rates Measured at Four Ventilation Levels

Subject	Location	Mean Inhalation Rate[a] (m^3/hr)[a] Low	Medium	Heavy	Very Heavy
All subjects	Indoor (Treadmill post)	1.23	1.83	3.13	4.13
	Outdoor	0.88	1.96	2.93	4.90
	Total	0.93	1.92	3.01	4.80

[a] Original data were presented in L/min. Conversion to m^3/hr was obtained as follows:

$$60\ \frac{min}{hr}\ x\ \frac{m^3}{1000L}\ x\ \frac{L}{min}$$

Source: Adapted from Shamoo et al., 1992

The population sample size used in this study was small and was not selected to represent the general U.S. population. The training approach employed may not be cost effective because it was labor intensive; therefore, this approach may not be viable in field studies especially for field studies within large sample sizes.

AIHC (1994) - The Exposure Factors Sourcebook - AIHC (1994) recommends an average adult inhalation rate of 18 m^3/day and presents values for children of various ages. These recommendations were derived from data presented in U.S. EPA (1989). The newer study by Layton (1993) was not considered. In addition, the Sourcebook presents probability distributions derived by Brorby and Finley (1993). For each distribution, the @Risk formula is provided for direct use in the @Risk simulation software (Palisade, 1992). The organization of this document makes it very convenient to use in support of Monte Carlo analysis. The reviews of the supporting studies are very brief with little analysis of their strengths and weaknesses. The Sourcebook has been classified as a relevant rather than key study because it is not the primary source for the data used to make recommendations in this document. The Sourcebook is very similar to this document in the sense that it summarizes exposure factor data and recommends values. As such, it is clearly relevant as an alternative information source on inhalation rates as well as other exposure factors.

5.2.4. Recommendations

In the Ozone Criteria Document prepared by the U.S. EPA Office of Environmental Criteria and Assessment, the EPA identified the collapsed range of activities and its corresponding VR as follows: light exercise (V_E < 23 L/min or 1.4 m^3/hr); moderate/ medium exercise (V_E= 24-43 L/min or 1.4-2.6 m^3/hr); heavy exercise (V_E= 43-63 L/min or 2.6-3.8 m^3/hr); and very heavy exercise (V_E> 64 L/min or 3.8 m^3/hr), (Adams, 1993).

Recent peer reviewed scientific papers and an EPA report comprise the studies that were evaluated in this Chapter. These studies were conducted in the United States among both men and women of different age groups. All are widely available. The confidence ratings in the inhalation rate recommendations are shown in Table 5-22.

Each study focused on ventilation rates and factors that may affect them. Studies were conducted among randomly selected volunteers. Efforts were made to include men, women, different age groups, and different kinds of activities. Measurement methods are indirect, but reproducible. Methods are well described (except for questionnaires) and experimental error is well

Table 5-22. Confidence in Inhalation Rate Recommendations

Considerations	Rationale	Rating
Study Elements		
• Peer Review	Studies are from peer reviewed journal articles and an EPA peer reviewed report.	High
• Accessibility	Studies in journals have wide circulation. EPA reports are available from the National Technical Information Service.	High
• Reproducibility	Information on questionnaires and interviews were not provided.	Medium
• Focus on factor of interest	Studies focused on ventilation rates and factors influencing them.	High
• Data pertinent to U.S.	Studies conducted in the U.S.	High
• Primary data	Both data collection and re-analysis of existing data occurred.	Medium
• Currency	Recent studies were evaluated.	High
• Adequacy of data collection period	Effort was made to collect data over time.	High
• Validity of approach	Measurements were made by indirect methods.	Medium
• Representativeness of the population	An effort has been made to consider age and gender, but not systematically.	Medium
• Characterization of variability	An effort has been made to address age and gender, but not systematically.	High
• Lack of bias in study design	Subjects were selected randomly from volunteers and measured in the same way.	High
• Measurement error	Measurement error is well documented by statistics, but procedures measure factor indirectly.	Medium
Other Elements		
• Number of studies	Five key studies and six relevant studies were evaluated.	
• Agreement between researchers	There is general agreement among researchers using different experimental methods.	High
Overall Rating	Several studies exist that attempt to estimate inhalation rates according to age, gender and activity.	High

documented. There is general agreement with these estimates among researchers.

The recommended inhalation rates for adults, children, and outdoor workers/athletes are based on the key studies described in this chapter (Table 5-23). Different survey designs and populations were utilized in the studies described in this Chapter. A summary of these designs, data generated, and their limitations/advantages are presented in Table 5-24. Excluding the study by Layton (1993), the population surveyed in all of the key studies described in this report were limited to the Los Angeles area. This regional population may not represent the general U.S. population and may result in biases. However, based on other aspects of the study design, these studies were selected as the basis for recommended inhalation rates.

The selection of inhalation rates to be used for exposure assessments depends on the age of the exposed population and the specific activity levels of this population during various exposure scenarios. The recommended values for adults, children (including infants), and outdoor workers/athletes for use in various exposure scenarios are discussed below. These rates were calculated by averaging the inhalation rates for each activity level from the various key studies (see Table 5-25).

Adults (19-65+ yrs) - Adults in this recommendation include young to middle age adults (19-64 yrs), and older adults (65+ yrs). The daily average inhalation rates for long term exposure for adults are: 11.3 m^3/day for women and 15.2 m^3/day for men. These values are averages of the inhalation rates provided for males and females in each of the three approaches of Layton (1993) (Tables 5-11 through 5-14). An upper percentile is not recommended. Additional research and analysis of activity pattern data and dietary data in the future is necessary to attempt to calculate upper percentiles.

The recommended value for the general population average inhalation rate, 11.3 m^3/day for women and 15.2 m^3/day for men, is different than the 20 m^3/day which has commonly been assumed in past EPA risk assessments. In addition, recommendations are presented for various ages and special populations (athletes, outdoor workers) which also differ from 20 m^3/day. Assessors are encouraged to use values which most accurately reflect the exposed population.

For exposure scenarios where the distribution of activity patterns is known, the following results, calculated from the studies referenced are shown in Table 5-25. Based on these key studies, the following recommendations are made: for short term exposures in

Table 5-23. Summary of Recommended Values for Inhalation

Population	Mean	Upper Percentile
Long-term Exposures		
Infants		
<1 year	4.5 m^3/day	---
Children		
1-2 years	6.8 m^3/day	---
3-5 years	8.3 m^3/day	---
6-8 years	10 m^3/day	---
9-11 years		
males	14 m^3/day	---
females	13 m^3/day	---
12-14 years		
males	15 m^3/day	---
females	12 m^3/day	---
15-18 years		
males	17 m^3/day	---
females	12 m^3/day	---
Adults (19-65+ yrs)		
females	11.3 m^3/day	---
males	15.2 m^3/day	---
Short-term Exposures		
Adults		
Rest	0.4 m^3/hr	---
Sedentary Activities	0.5 m^3/hr	---
Light Activities	1.0 m^3/hr	---
Moderate Activities	1.6 m^3/hr	---
Heavy Activities	3.2 m^3/hr	---
Children		
Rest	0.3 m^3/hr	---
Sedentary Activities	0.4 m^3/hr	---
Light Activities	1.0 m^3/hr	---
Moderate Activities	1.2 m^3/hr	---
Heavy Activities	1.9 m^3/hr	---
Outdoor Workers		
Hourly Average	1.3 m^3/hr	3.3 m^3/hr
Slow Activities	1.1 m^3/hr	
Moderate Activities	1.5 m^3/hr	
Heavy Activities	2.5 m^3/hr	

Note: See Tables 5-25, 5-26, and 5-27 for reference studies.

which distribution of activity patterns are specified, the recommended average rates are 0.4 m^3/hr during rest; 0.5 m^3/hr for sedentary activities; 1.0 m^3/hr for light activities; 1.6 m^3/hr for moderate activities; and 3.2 m^3/hr for heavy activities.

Children (18 yrs old or less including infants) - For the purpose of this recommendation, children are defined as males and females between the ages of 1-18 years old, while infants are individuals less than 1 year old. The inhalation rates for children are presented below according to different exposure scenarios. The daily inhalation rates for long-term dose assessments, are based on the first approach of Layton (1993) (Table 5-11) and are summarized in Table 5-26.

Based on the key study results (i.e., Layton, 1993), the recommended daily inhalation rate for infants (children less than 1 yr), during long-term dose assessments is 4.5 m^3/day. For children 1-2 years old, 3-5 years old, and 6-8 years old, the recommended daily inhalation rates are 6.8 m^3/day, 8.3 m^3/day, and 10 m^3/day, respectively. Recommended values for children aged 9-11 years are 14 m^3/day for males and 13 m^3/day for females. For children aged 12-14 years and 15-18 years, the recommended values are shown in Table 5-23.

For short-term exposures for children aged 18 years and under, in which activity patterns are known, the data are summarized in Table 5-27. For short term exposures, the recommended average hourly inhalation rates are based on these key studies. They are averaged over each activity held as follows: 0.3 m^3/hr during rest; 0.4 m^3/hr for sedentary activities; 1.0 m^3/hr for light activities; 1.2 m^3/hr for moderate activities; and 1.9 m^3/hr for heavy activities. The recommended short-term exposure data also include infants (less than 1 yr). These values represent averages of the activity level data from key studies (Table 5-27).

Outdoor Worker - Inhalation rate data for outdoor workers/athlete are limited. However, based on the key studies (Linn et al., 1992 and 1993), the recommended average hourly inhalation rate for outdoor workers is 1.3 m^3/hr and the upper-percentile rate is 3.3 m^3/hr (see Tables 5-5 and 5-8). This is calculated as the weighted mean of the 99th percentile values reported for the individuals on Panels 1 and 7 in Tables 5-5 and the 19 subjects in Table 5-8. The recommended average inhalation rates for outdoor workers based on the activity levels categorized as slow (light activities), medium (moderate activities), and fast (heavy activities) are 1.1 m^3/hr, 1.5 m^3/hr, and 2.5 m^3/hr, respectively. These values are based on the data from Linn et al. (1992 and 1993) and are the weighted mean of the values for the individuals on Panels 1 and 7 in Table 5-5 and the 19 outdoor workers in Table 5-9. Inhalation rates may be higher among outdoor workers/athletes because levels of activity outdoors may be higher. Therefore, this subpopulation group may be more susceptible to air pollutants and are considered a "high-risk" subgroup (Shamoo et al., 1991; Linn et al., 1992).

Table 5-24. Summary of Inhalation Rate Studies

Study	Population Surveyed	Survey Time Period	Data Generated	Limitations/Advantages
KEY INHALATION RATE STUDIES				
Adams, 1993	n=160, ages 6-77; n = 40, ages 3-12.	Three 25 min phases of resting protocol in the lab 6 mins of active protocols in the lab. 30 min phases of field protocols repeated once.	Mean values of IR for adult males and females and children by their activity levels.	HR correlated poorly with IR.
Layton, 1993	NFCS survey: n≈30,000; NHANES survey: n≈20,000 Time Activity survey: n≈2,126		Daily IRs; IRs at 5 activity levels; and IR for short-term exposures at 5 activity levels.	Reported food biases in the dietary surveys employed; time activity survey was based on recall.
Linn et al., 1992	Panel 1 - 20 healthy outdoor workers, ages 19-50; Panel 2 - 17 healthy elementary school students, ages 10-12; Panel 3 - 19 healthy high school students, ages 13-17; Panel 4 - 49 adult asthmatics, ages 18-50; Panel 5 - 24 adult asthmatics, ages 19-46; Panel 6 - 13 young asthmatics, ages 11-16; Panel 7 - 7 construction workers, ages 26-34.	Late spring and early autumn. 3 diary days. Construction workers' diary day.	Mean and upper estimates of IR; Mean IR at 3 activity levels.	Small sample size; Calibration data not obtained over full HR range; activities based on short-term diary data.
Linn et al., 1993	n=19 construction workers.	(Mid-July-early November, 1991) Diary recordings before work, during work and break times	Distribution patterns of hourly IR by activity level.	Small sample population size; breathing rates subjective in nature; activities based on short-term diary data.
Spier et al., 1992	n=36 students, ages 10-17.	(Late September - October) Involved 3 consecutive days of diary recording	Distribution patterns of hourly IR by activity levels and location	Activities based on short-term diary data; self-estimated breathing rate by younger population was biased; small sample population size.
RELEVANT INHALATION RATE STUDIES				
ICRP, 1974	Based on data from other references	--	Reference daily IR for adult females, adult males, children (10 yrs), and infant (1 yr)	Validity and accuracy of data set employed not defined; IR was estimated not measured.
Shamoo et al., 1990	n=9 volunteer workers ages 21-37, n=20 outdoor workers, 19-50 years old.	Involved 3-min indoor session/two 3-hr outdoor session at 4 activity levels	No IR data presented.	No useful data were presented for dose assessments studies.
Shamoo et al., 1991	n=20 outdoor workers, ages 19-50	Diary recordings of three 24-hr. periods within a week.	Distribution patterns of IR and EVR by activity levels and location.	Small sample size; short-term diary data.
Shamoo et al., 1992	n=9 non-sedentary subjects, ages 21-37.	3-min. intervals of indoor exercises/two 3-hr outdoor exercise sessions at 4 activity levels.	Actual measured ventilation rates presented.	Small sample size; training approach may not be cost-effective; VR obtained for outdoor workers which are sensitive subpopulation.
U.S. EPA, 1985	Based on data from several literature sources	--	Estimated IR for adult males, adult females and children (ages 6 and 10) by various activity levels.	Validity and accuracy of data set employed not defined; IR was estimated not measured.

Note: IR = inhalation rate; HR = heart rate; EVR = equivalent ventilation rate.

Table 5-25. Summary of Adult Inhalation Rates for Short-Term Exposure Studies					
		Arithmetic Mean (m^3/hr) Activity Level			
Rest	Sedentary	Light	Moderate	High	Reference
0.5	0.5	1.4	2.4	3.3	Adams, 1993 (Lab protocols)
--	0.6	1.2	1.8	--	Adams, 1993 (Field protocols)
0.4	0.4	0.7	1.4	3.6	Layton, 1993 (Short-term exposure)
0.4	--	0.6	1.5	3.0	Layton, 1993 (3rd approach)
--	--	1.0	1.6	3.0	Linn et al., 1992

Table 5-26. Summary of Children's (18 years old or less) Inhalation Rates for Long-Term Exposure Studies[a]				
	Arithmetic Mean (m^3/day)			
Age	Males	Females	Males and Females	Reference
less than 1 yr	--	--	4.5	Layton, 1993
1-2 years	--	--	6.8	Layton, 1993
3-5 years	--	--	8.3	Layton, 1993
6-8 years	--	--	10	Layton, 1993
9-11 years	14	13	--	Layton, 1993
12-14 years	15	12	--	Layton, 1993
15-18 years	17	12	--	Layton, 1993

[a] Layton, 1993 1st approach.

Table 5-27. Summary of Children's Inhalation Rates for Short-Term Exposure Studies					
		Arithmetic Mean (m^3/hr) Activity Level			
Rest	Sedentary	Light	Moderate	High	Reference
0.4	0.4	0.8	--	--	Adams, 1993 (Lab protocols)
--	--	--	0.9	--	Adams, 1993 (Field protocols)
0.2	0.3	0.5	1.0	2.5	Layton, 1993 (Short-term data)
--	--	1.8	2.0	2.2	Spier et al., 1992 (10-12 yrs)
--	--	0.8	1.0	11	Linn et al., 1992 (10-12 yrs)

5.3. REFERENCES FOR CHAPTER 5

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APPENDIX 5A

VENTILATION DATA

Table 5A-1. Mean Minute Ventilation (V_E, L/min) by Group and Activity for Laboratory Protocols

Activity		Young Children[a]	Children	Adult Females	Adult Males
Lying		6.19	7.51	7.12	8.93
Sitting		6.48	7.28	7.72	9.30
Standing		6.76	8.49	8.36	10.65
Walking	1.5 mph	10.25	DNP	DNP	DNP
	1.875 mph	10.53	DNP	DNP	DNP
	2.0 mph	DNP	14.13	DNP	DNP
	2.25 mph	11.68	DNP	DNP	DNP
	2.5 mph	DNP	15.58	20.32	24.13
	3.0 mph	DNP	17.79	24.20	DNP
	3.3 mph	DNP	DNP	DNP	27.90
	4.0 mph	DNP	DNP	DNP	36.53
Running	3.5 mph	DNP	26.77	DNP	DNP
	4.0 mph	DNP	31.35	46.03[b]	DNP
	4.5 mph	DNP	37.22	47.86[b]	57.30
	5.0 mph	DNP	DNP	50.78[b]	58.45
	6.0 mph	DNP	DNP	DNP	65.66[b]

[a] Young Children, male and female 3-5.9 yr olds; Children, male and female 6-12.9 yr olds; Adult Females, adolescent, young to middle-aged, and older adult females; Adult Males, adolescent, young to middle-aged, and older adult males; DNP, group did not perform this protocol or N was too small for appropriate mean comparisons

[b] Older adults not included in the mean value since they did not perform running protocol at particular speeds.

Source: Adams, 1993.

Table 5A-2. Mean Minute Ventilation (V_E, L/min) by Group and Activity for Field Protocols

Activity	Young Children[a]	Children	Adult Females	Adult Males
Play	11.31	17.89	DNP	DNP
Car Driving	DNP	DNP	8.95	10.79
Car Riding	DNP	DNP	8.19	9.83
Yardwork	DNP	DNP	19.23[e]	26.07[b]/31.89[c]
Housework	DNP	DNP	17.38	DNP
Car Maintenance	DNP	DNP	DNP	23.21[d]
Mowing	DNP	DNP	DNP	36.55[e]
Woodworking	DNP	DNP	DNP	24.42[e]

[a] Young Children, male and female 3-5.9 yr olds; Children, male and female 6-12.9 yr olds; Adult Females, adolescent, young to middle-aged, and older adult females; Adult Males, adolescent, young to middle-aged, and older adult males; DNP, group did not perform this protocol or N was too small for appropriate mean comparisons;

[b] Mean value for young to middle-aged adults only

[c] Mean value for older adults only

[d] Older adults not included in the mean value since they did not perform this activity.

[e] Adolescents not included in mean value since they did not perform this activity

Source: Adams, 1993.

Table 5A-3. Characteristics of Individual Subjects: Anthropometric Data, Job Categories, Calibration Results

Subj. #	Age (years)	Ht. (in.)	Wt. (lb.)	Ethnic Group[a]	Job[b]	Site[c]	Calibration HR Range[d]	Calibration r^2[e]
1761	26	71	180	Wht	GCW	Ofc	69-108	.91
1763	29	63	135	Asn	GCW	Ofc	80-112	.95
1764	32	71	165	Blk	Car	Ofc	56-87	.95
1765	30	73	145	Wht	GCW	Ofc	66-126	.97
1766	31	67	170	His	Car	Ofc	75-112	.89
1767	34	74	220	Wht	Car	Ofc	59-114	.98
1768	32	69	155	Blk	GCW	Ofc	62-152	.95
1769	32	77	230	Wht	Car	Hosp	69-132	.99
1770	26	70	180	Wht	Car	Hosp	63-106	.89
1771	39	66	150	Wht	Car	Hosp	88-118	.91
1772	32	71	260	Wht	Car	Hosp	83-130	.97
1773	39	69	170	Wht	Irn	Hosp	77-128	.95
1774	23	68	150	His	Car	Hosp	68-139	.98
1775	42	67	150	Wht	Irn	Hosp	76-118	.88
1776	29	70	180	His	Car	Hosp	68-152	.99
1778	35	76	220	Ind	Car	Hosp	70-129	.94
1779	40	70	175	Wht	Car	Hosp	72-140	.99
1780	37	75	242	His	Irn	Hosp	68-120	.98
1781	38	65	165	His	Lab	Hosp	66-121	.89
Mean	33	70	181				70-123	.94
SD	5	4	36				8-16	.04

[a] Abbreviations are interpreted as follows. Ethnic Group: Asn = Asian-Pacific, Blk = Black, His = Hispanic, Ind = American Indian, Wht = White
[b] Job: Car = carpenter, GCW = general construction worker, Irn = ironworker, Lab = laborer
[c] Site: Hosp = hospital buidling, Ofc = medical office complex. Calibration data
[d] HR range = range of heart rates in calibration study
[e] r^2 = coefficient of determination (proportion of ventilation rate variability explainable by heart rate variability under calibration-study conditions, using quadratic prediction equation).
Source: Linn et al., 1993.

Table 5A-4. Statistics of the Age/Gender Cohorts Used to Develop Regression Equations for Predicting Basal Metabolic Rates (BMR)

Gender/Age (y)	BMR MJ d^{-1}	BMR ±SD	CV[a]	Body Weight (kg)	N[b]	BMR Equation[c]	r[d]
Males							
Under 3	1.51	0.918	0.61	6.6	162	0.249 bw - 0.127	0.95
3 to < 10	4.14	0.498	0.12	21	338	0.095 bw + 2.110	0.83
10 to < 18	5.86	1.171	0.20	42	734	0.074 bw + 2.754	0.93
18 to < 30	6.87	0.843	0.12	63	2879	0.063 bw + 2.896	0.65
30 to < 60	6.75	0.872	0.13	64	646	0.048 bw + 3.653	0.6
60 +	5.59	0.928	0.17	62	50	0.049 bw + 2.459	0.71
Females							
Under 3	1.54	0.915	0.59	6.9	137	0.244 bw - 0.130	0.96
3 to < 10	3.85	0.493	0.13	21	413	0.085 bw + 2.033	0.81
10 to < 18	5.04	0.780	0.15	38	575	0.056 bw + 2.898	0.8
18 to < 30	5.33	0.721	0.14	53	829	0.062 bw + 2.036	0.73
30 to < 60	5.62	0.630	0.11	61	372	0.034 bw + 3.538	0.68
60 +	4.85	0.605	0.12	56	38	0.038 bw + 2.755	0.68

[a] Coefficient of variation (SD/mean)
[b] N = number of subjects
[c] Body weight (bw) in kg
[d] coefficient of correlation
Source: Layton, 1993.

Table 5A-5. Selected Ventilation Values During Different Activity Levels Obtained From Various Literature Sources

Col.	1	2	3			4			5			6		
Line	Subject	W (kg)	Resting			Light Activity			Heavy Work			Maximal Work During Exercise		
			f	VT	V*	f	VT	V*	f	VT	V*	f	VT	V*
	Adult													
1	Man	68.5	12	750	7.4	17	1670	29	21	2030	43			
2	1.7 m² SA		12	500	6									
3	30y; 170 cm L		15	500	7.5	16	1250	20						
4	20-33 y	70.4										40	3050	111
5	Woman	54	12	340	4.5	19	860	16	30	880	25			
6	30 y; 160 cm L		15	400	6	20	940	19						
7	20-25 y; 165.8 cm L	60.3										46	2100	90
8	Pregnant (8th mo)		16	650	10									
	Adolescent													
9	male, 14-16 y		16	330	5.2							53	2520	113
10	male, 14-15 y	59.4												
11	female, 14-16 y		15	300	4.5									
12	female, 14-15 y; 164.9 cm L	56										52	1870	88
	Children													
13	10 y; 140 cm L		16	300	4.8	24	600	14						
14	males, 10-11 y	36.5										58	1330	71
15	males, 10-11 y; 140.6 cm L	32.5										61	1050	61
16	females, 4-6 y	20.8										70	600	40
17	females, 4-6 y; 111.6 cm L	18.4										66	520	34
18	Infant, 1 y		30	48	1.4[a]									
19	Newborn	2.5	34	15	0.5									
20	20 hrs-13 wk	2.5-5.3										68[b]	51[a,b]	3.5[b]
21	9.6 hrs	3.6	25	21	0.5									
22	6.6 days	3.7	29	21	0.6									

W = body weights referable to the dimension quoted in column 1; f = frequency (breaths/min); VT = tidal volume (ml); V* = minute volume (l/min); SA = surface area; cm L = length/height; y = years of age; wk = week.

[a] Calculated from V* = f x VT.
[b] Crying.

Source: ICRP, 1981.

Table 5A-5. Selected Ventilation Values During Different Activity Levels Obtained From Various Literature Sources

Col.	1	2	3			4			5			6		
Line	Subject	W (kg)	Resting			Light Activity			Heavy Work			Maximal Work During Exercise		
			f	VT	V*	f	VT	V*	f	VT	V*	f	VT	V*
	Adult													
1	Man	68.5	12	750	7.4	17	1670	29	21	2030	43			
2	1.7 m^2 SA		12	500	6									
3	30y; 170 cm L		15	500	7.5	16	1250	20						
4	20-33 y	70.4										40	3050	111
5	Woman	54	12	340	4.5	19	860	16	30	880	25			
6	30 y; 160 cm L		15	400	6	20	940	19						
7	20-25 y; 165.8 cm L	60.3										46	2100	90
8	Pregnant (8th mo)		16	650	10									
	Adolescent													
9	male, 14-16 y		16	330	5.2							53	2520	113
10	male, 14-15 y	59.4												
11	female, 14-16 y		15	300	4.5									
12	female, 14-15 y; 164.9 cm L	56										52	1870	88
	Children													
13	10 y; 140 cm L		16	300	4.8	24	600	14						
14	males, 10-11 y	36.5										58	1330	71
15	males, 10-11 y; 140.6 cm L	32.5										61	1050	61
16	females, 4-6 y	20.8										70	600	40
17	females, 4-6 y; 111.6 cm L	18.4										66	520	34
18	Infant, 1 y		30	48	1.4[a]									
19	Newborn	2.5	34	15	0.5									
20	20 hrs-13 wk	2.5-5.3										68[b]	51[a,b]	3.5[b]
21	9.6 hrs	3.6	25	21	0.5									
22	6.6 days	3.7	29	21	0.6									

W = body weights referable to the dimension quoted in column 1; f = frequency (breaths/min); VT = tidal volume (ml); V* = minute volume (l/min); SA = surface area; cm L = length/height; y = years of age; wk = week.

[a] Calculated from V* = f x VT.
[b] Crying.

Source: ICRP, 1981.

Table 5A-6. Estimated Minute Ventilation Associated with Activity Level for Average Male Adult[a]

Level of work	L/min	Representative activities
Light	13	Level walking at 2 mph; washing clothes
Light	19	Level walking at 3 mph; bowling; scrubbing floors
Light	25	Dancing; pushing wheelbarrow with 15-kg load; simple construction; stacking firewood
Moderate	30	Easy cycling; pushing wheelbarrow with 75-kg load; using sledgehammer
Moderate	35	Climbing stairs; playing tennis; digging with spade
Moderate	40	Cycling at 13 mph; walking on snow; digging trenches
Heavy Heavy Very heavy	55 63 72	Cross-country skiing; rock climbing; stair climbing with load; playing squash or handball; chopping with axe
Very heavy	85	Level running at 10 mph; competitive cycling
Severe	100+	Competitive long distance running; cross-country skiing

[a] Average adult assumed to weigh 70 kg.
Source: Adapted from U.S. EPA, 1985

Table 5A-7. Minute Ventilation Ranges by Age, Sex, and Activity Level

Age	Sex	Resting			Light			Moderate			Heavy		
		Ventilation ranges (liters/minute)											
(years)		n	Range	Mean	n	Range	Mean	n	Range	Mean	n	Range	Mean
Infants	M/F	316	0.25 - 2.09	0.84					---			---	
2	F		---			---			---			---	
	M		---			---			---			---	
3	F		---			---			---			---	
	M		---			---			---			---	
4	F		---			---			---		2	32.0 - 32.5	32.3
	M		---			---			---		4	39.3 - 43.3	41.2
5	F		---			---			---		3	31.0 - 35.0	32.8
	M		---			---			---		3	30.9 - 42.6	37.5
6	F		---			---			---		2	35.9 - 38.9	37.4
	M	8	5.0 - 7.0	6.5	16	5.0 - 32.0	13.9	4	28.0 - 43.0	33.3	3	35.5 - 43.5	40.3
7	F		---			---			---		3	48.2 - 51.4	49.6
	M		---			---			---		2	44.1 - 55.8	50.0
8	F		---			---			---		4	51.2 - 67.6	57.6
	M		---			---			---		3	59.3 - 62.2	60.7
9	F		---			---			---		27	55.8 - 63.4	50.9
	M		---			---			---		7	59.5 - 75.2	65.7
10	F		---			---			---		21	46.2 - 71.1	60.4
	M	10	5.2 - 8.3	7.1	20	5.2 - 35.0	17.2	9	41.0 - 68.0	53.4	6	63.9 - 74.6	70.5
	F		---			---			---		7	49.7 - 80.9	63.5
	M		---		20	---	20.3	20	---	33.1	9	47.6 - 77.5	65.5
12	F	54	4.1 - 16.1	15.4		---		4	19.6 - 46.3	26.5	31	65.5 - 79.9	71.8
	M	56	7.2 - 16.3	15.4		---		6	18.5 - 46.3	34.1	9	58.1 - 84.7	67.7
13	F	5	7.2 - 15.4	9.9		---		5	18.5 - 46.3	30.3	7	67.6 - 102.6	87.7
	M	16	3.1 - 15.4	8.9	30	3.1 - 24.9	16.4	29	14.4 - 48.4	32.8	38	27.8 - 105.0	57.9
14	F	53	3.1 - 15.6	14.9		---		3	21.6 - 37.1	28.1	5	80.7 - 100.7	88.9
	M	77	3.1 - 27.8	14.2		---		24	24.7 - 55.0	39.7	16	42.2 - 121.0	86.9
15	F	1	---	6.2		---		1	---	26.8	6	68.4 - 97.1	87.1
	M	8	3.1 - 26.8	11.1		---		7	27.8 - 46.3	39.3	6	48.4 - 140.3	110.5
16	F	50	---	15.2		---	---		---		8	73.6 - 119.1	93.9
	M	50	---	15.6		---			---		3	79.6 - 132.2	102.5
17	F		---			---			---		2	91.9 - 95.3	93.6
	M	12	5.8 - 9.0	7.3		---		12	40.0 - 63.0	48.6	3	89.4 - 139.3	107.7
18	F		---			---			---			---	
	M		---			---			---		9	99.7 - 143.0	120.9
Adults	F	595	4.2 - 11.66	5.7	786	4.2 - 29.4	8.1	106	20.7 - 34.2	26.5	211	23.4 - 114.8	47.9
Adults	M	454	2.3 - 18.8	12.2	102	2.3 - 27.6	13.8	102	14.4 - 78.0	40.9	267	34.6 - 183.4	80.0

n = number of observations

Note: Values in liters/minute can be converted to units of m^3/hour by multiplying by the conversion factor $\frac{60\ \text{minutes/hour}}{1000\ \text{liters/m}^3}$

Source: Adapted from U.S. EPA, 1985.